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EDITOR

CONTENTS

- | | |
|----|--|
| 1 | The Role of Rigor in the Teaching of Mechanics
Henry L. Langhaar, Professor
Department of Theoretical and Applied Mechanics
University of Illinois—Urbana |
| 11 | Demonstrations to Aid Teaching of Mechanical Vibrations
Raymond A. Willem, Assistant Professor
Department of Mechanical Engineering
New Mexico State University |
| 17 | MECHAIDS—A Self-Paced Remedial Learning Tool
James K. Strozier, Assoc. Prof. and Robert M. Wilson,
Prof.
Department of Mechanics
United States Military Academy |
| 31 | Prof. Z. Freebody Snafu
Elmer L. Munger, Professor
Department of Civil Engineering
Michigan Technological University |
| 32 | The Mechanics of Vehicular Safety
Richard P. McNitt and James H. Sword, Professors
Department of Engineering Science and Mechanics
Virginia Polytechnic Institute and State University |
| 42 | The Place of Engineering Mechanics Faculty in Engineering Mechanics Programs
Verne C. Cutler, Professor of Engineering Mechanics
University of Wisconsin—Milwaukee |
| 47 | Three Score and Ten
Archie Higdon, Consultant in Engineering and Technical
Education
San Luis Obispo, CA |

The Role of Rigor in the Teaching of Mechanics

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RIGOR AND UNDERSTANDING

In the preface to his book, *General Mechanics*, Max Planck* said: "I have frequently observed that the difficulties with which the student has to contend when he first enters the realm of theoretical physics are more often concerned, not with the mathematical form, but with the physical content of the ideas that are presented to him. It is not the calculations with equations that cause him the most trouble, but the setting up of the equations, and, in particular, their interpretation." Knowledge of engineering mechanics implies more than the ability to derive and interpret the basic equations of mechanics. It signifies the ability to apply the principles of mechanics to various physical systems, and thereby to predict the mechanical behavior of the systems correctly. Experience plays an important part in the development of such understanding, but the first requisite is an insight into the principles of mechanics. Planck's imaginative and deductive treatment of classical physics, illuminated by an easy style, displays mathematics, not as a tool, but rather as the language of physics. The role of rigor in mechanics is partly the cultivation of understanding and fluency in this language.

According to the dictionary, rigor means strictness or severity. Rigor, in this sense, whether self-imposed or enforced by authorities, is essential for learning. Students like a teacher who is a good fellow, but they are apt to learn more from one who insists on complete explanations, clear reasoning, neatness, and accuracy.

However, in the present context, rigor is not viewed from the standpoint of the disciplinarian, important though that may be. In mathematics, rigor means strict adherence to certain principles of reasoning. It does not mean ultimate logic, for that may be unknowable; at least, it still eludes philosophers and mathematicians. Despite misgivings aroused by Goedel's famous demonstration that a postulational approach to a science may enmesh us in inconsistencies and deny us access to certain truths, rigor in mathematics generally is interpreted

* *General Mechanics*, MacMillan Co., New York, 1932.

to imply the axiomatic method. D. Hilbert said: "I think that everything that can be an object of scientific study at all, as soon as it is ripe for the formation of a theory, falls into the lap of the axiomatic method and thereby indirectly of mathematics. Under the banner of the axiomatic method, mathematics seems destined for a leading role in science." The axiomatic method originated in classical Greece, but it was not understood clearly until this century.

Following the pattern of Euclid, Newton attempted an axiomatic development of mechanics. Not surprisingly, his reasoning contains the same kinds of flaws that logicians now perceive in Euclid's work. Von Mises[†] has commented on this: "There are two new basic concepts that enter into the construction of Newtonian mechanics—those of force and mass. Newton explains mass in his first definition as 'quantity of matter.' One notices immediately that this definition is completely empty and in no way helps us to gain an understanding of the phenomena of motion. All one has to do is reflect that it would be possible to substitute the words 'quantity of matter' for the word 'mass' wherever it appears in a contemporary text. Newton's definition of force largely anticipates the content of the first two laws of motion: the force neither changes the location of a body (immediately), nor determines the velocity, but rather *changes its velocity*. Thus, force is first defined as something that changes the velocity, and then the law is stated that velocities are changed by forces. This manner of inference has been well put by Molière: 'The poppy seed is soporiferous; why?—because it has the power of soporificity.' But scoffing here is ill-advised, for Newton's Principia expresses one of the most far-reaching and original discoveries ever made in physics."

TIME AND KINEMATICS

The axiomatic method has had its most striking successes in geometry. Characteristically, axiomatic theories deal with undefined elements. For example, in the treatise on projective geometry by Veblen and Young, a point is undefined. A line is said to be an undefined set of points, except insofar as it is defined implicitly by certain postulates; e.g., two distinct points are on one and only one line; there are more than two points on a line, etc. A far-reaching hierarchy of theorems issues from such simple postulates.

Newton was aware that an axiomatic theory necessarily contains some undefined elements. In his Principia, he states that time, space, motion, and location do not require definition. The public has recognized vaguely, since the popularization of Einstein's theory, that our innate concept of time is wrong, or, at least, inappropriate for cosmology. However, this circumstance calls for no apologia, since, insofar as an axiomatic theory of Newtonian mechanics is concerned, the meaning of time is irrelevant. Consequently, the burden of defining and measuring time is transferred to philosophers and experimenters. For example, suppose that a position vector $\mathbf{r}$ is a function of an undefined parameter t ; i.e., $\mathbf{r} = \mathbf{r}(t)$. This vector equation defines a curve C . Vectors $\mathbf{v}$ and $\mathbf{a}$ are defined by

$\mathbf{v} = d\mathbf{r}/dt$ and $\mathbf{a} = d\mathbf{v}/dt$. Then, by differential geometry, $\mathbf{v}$ is tangent to curve C , and $v = ds/dt$, where s is arc length on C . Furthermore,

$$\mathbf{a} = \frac{d\mathbf{v}}{dt} = \frac{d\mathbf{v}}{ds} \frac{ds}{dt} = \mathbf{v} \frac{d\mathbf{v}}{ds} = \mathbf{v} \frac{d}{ds} (v\hat{\mathbf{v}}) = v^2 \frac{d\hat{\mathbf{v}}}{ds} + \mathbf{v} \frac{dv}{ds}$$

in which $\mathbf{v} = v\hat{\mathbf{v}}$; i.e., $\hat{\mathbf{v}}$ is the unit tangent vector of C . One of the formulas of Frenet in the differential geometry of curves is $d\hat{\mathbf{v}}/ds = \hat{\mathbf{n}}/R$, in which $\hat{\mathbf{n}}$ is the principal unit normal vector of C , and $1/R$ is the curvature of C . Consequently,

$$\mathbf{a} = \hat{\mathbf{n}} \frac{v^2}{R} + \hat{\mathbf{v}} \frac{dv}{ds} \quad \text{or} \quad \mathbf{a} = \hat{\mathbf{n}} \frac{v^2}{R} + \hat{\mathbf{v}} \frac{dv}{dt}$$

Accordingly, $\mathbf{a}$ lies in the osculating plane of curve C . The component of $\mathbf{a}$ on the principal normal is v^2/R and the component of $\mathbf{a}$ on the tangent to C is $dv/dt = d^2s/dt^2$. These are familiar results. The point is that the concept of time plays no role whatever in the deductions; t could be the x -coordinate, arc length on the curve, distance from the origin, or any other parameter.

Kinematics of a rigid body is essentially the theory of transformations of rectangular coordinates, in which the direction cosines of one set of axes with respect to the other are functions of a parameter t . If the two coordinate systems (x, y, z) and (ξ, η, ζ) have a common origin (which is no essential restriction, since translation is easily superimposed), and if the table of direction cosines is

	x	y	z
ξ	l_1	m_1	n_1
η	l_2	m_2	n_2
ζ	l_3	m_3	n_3

we obtain, by differentiating the equations of coordinate transformation, $\dot{x} = \dot{l}_1\xi + \dot{l}_2\eta + \dot{l}_3\zeta$, $\dot{y} = \dots$, $\dot{z} = \dots$, provided that the point under consideration has constant coordinates (ξ, η, ζ) . If we eliminate (ξ, η, ζ) from these equations by means of the equations of coordinate transformation,

$$\xi = l_1x + m_1y + n_1z, \dots, \dots,$$

and simplify the resulting equations by means of the equations,

$$l_1\dot{l}_1 + l_2\dot{l}_2 + l_3\dot{l}_3 = 0, \dots, \dots$$

$$l_1\dot{m}_1 + l_2\dot{m}_2 + l_3\dot{m}_3 = -m_1\dot{l}_1 - m_2\dot{l}_2 - m_3\dot{l}_3, \dots, \dots$$

which result by differentiation of algebraic identities among the direction cosines, we obtain

$$\dot{x} = z\omega_y - y\omega_z, \dot{y} = x\omega_z - z\omega_x, \dot{z} = y\omega_x - x\omega_y \quad (a)$$

where, by definition,

$$\omega_x = m_1\dot{n}_1 + m_2\dot{n}_2 + m_3\dot{n}_3$$

$$\omega_y = n_1\dot{l}_1 + n_2\dot{l}_2 + n_3\dot{l}_3$$

$$\omega_z = l_1\dot{m}_1 + l_2\dot{m}_2 + l_3\dot{m}_3 \quad (b)$$

[†] Mathematical Postulates and Human Understanding, The World of Mathematics, vol. 3, edited by J. R. Newman, Simon & Schuster, New York, 1956.

In modern engineering mechanics texts, Eq. (a) usually is derived in the vector notation $\mathbf{v} = \boldsymbol{\omega} \times \mathbf{r}$ by reference to a vector diagram. However, that approach does not provide Eq. (b), which is needed to prove that $\boldsymbol{\omega}$ is a vector. If we introduce new initial coordinates (x', y', z') with constant direction cosines, given by

	x	y	z
x'	a_1	b_1	c_1
y'	a_2	b_2	c_2
z'	a_3	b_3	c_3

and if, by analogy to Eq. (a), we define $(\omega'_x, \omega'_y, \omega'_z)$ by

$$\dot{x}' = z'\omega'_y - y'\omega'_z, \dot{y}' = x'\omega'_z - z'\omega'_x, \dot{z}' = y'\omega'_x - x'\omega'_y \quad (c)$$

the proof that angular velocity is a vector is equivalent to showing that it transforms like (dx, dy, dz) ; i.e.,

$$\omega'_x = a_1\omega_x + b_1\omega_y + c_1\omega_z, \dots, \dots \quad (d)$$

Surprisingly, Eq. (d) does not follow from Eqs. (a), (c), and the equations of coordinate transformation, $x' = a_1x + b_1y + c_1z, \dots, \dots$. These equations yield

$$\begin{aligned} \dot{x}' &= a_1\dot{x} + b_1\dot{y} + c_1\dot{z} = a_1(z\omega_y - y\omega_z) + b_1(x\omega_z - z\omega_x) \\ &\quad + c_1(y\omega_x - x\omega_y) = (a_3x + b_3y + c_3z)\omega'_y - (a_2x + b_2y + c_2z)\omega'_z, \\ &\quad \dots, \dots \end{aligned} \quad (e)$$

Equations (e) do not determine $(\omega'_x, \omega'_y, \omega'_z)$ uniquely because their determinant is zero. Their matrix is of rank 2. Because of identities among the direction cosines, the rank of the augmented matrix also is 2. One solution of Eq. (e) is Eq. (d). However, there are infinitely many solutions. We can let ω'_z be any function of (x, y, z) at pleasure, and solve Eqs. (e) for ω'_x and ω'_y . Consequently, something more than Eq. (a) and the equations of coordinate transformation from (x, y, z) to (x', y', z') is required to verify that angular velocity is a vector. The information that is needed is contained by Eq. (b).

The concepts of time and motion do not enter into the preceding analysis. In fact, the entire theory of kinematics of a rigid body may be regarded as geometry. Likewise, the philosophic interpretation of time is irrelevant in the kinematics of fluids. This is apparent if the displacement of a fluid is represented in the Lagrangian form, $\mathbf{r} = \mathbf{f}(\mathbf{r}_0, t)$, in which t is any parameter, and $\mathbf{f}(\mathbf{r}_0, 0) = \mathbf{r}_0$. The velocity field is defined by $\mathbf{v} = \partial \mathbf{r} / \partial t$, and the acceleration field by $\mathbf{a} = \partial \mathbf{v} / \partial t$. The continuity equation for fluids remains valid if t is any parameter.

MASS AND THE LAWS OF DYNAMICS

It has been shown that time plays the role of an arbitrary scalar parameter in Newtonian kinematics. Mass is another scalar that may be defined incompletely in a postulational treatment of mechanics. Despite von Mises' critique of Newton's argument, the concept of mass as quantity of matter properly conveys the idea that mass is independent of gravity. On the basis of the atomic theory,

quantity of matter may be defined as a measure of the numbers of protons and neutrons in a system.

The mass of a system is the sum of the masses of its parts. A mechanical system may be conceived as a set of particles, which generally is non-enumerable. In the language of mathematics, a configuration of the system is represented by a bounded Borel point set B . A subset of B has mass m . If we emulate the rigour of modern mathematics, we specify that m is a non-negative additive set function defined on all Borel subsets of B . The function m is invariant, in the sense that it is unchanged by a displacement of the system, i.e., m has the same value for all sets that are equivalent under the family of mappings $\mathbf{r} = \mathbf{f}(\mathbf{r}_0, t)$.

A velocity field $\mathbf{v}$ on the point set B is defined by $\mathbf{v} = \partial \mathbf{r} / \partial t$, and the momentum of system B is defined by

$$\mathbf{G} = \int_B \mathbf{v} \, dm,$$

in which, for inclusion of point masses in the system and other generalities, the integral should be interpreted in the Lebesgue-Stieltjes sense. Also, the angular momentum of the system about the origin is defined by

$$\mathbf{H} = \int_B \mathbf{r} \times \mathbf{v} \, dm$$

The fundamental equations of Newtonian dynamics are

$$\mathbf{F} = \frac{d\mathbf{G}}{dt}, \mathbf{M} = \frac{d\mathbf{H}}{dt} \quad (f)$$

These equations may be regarded as postulates. Since Newton's second law follows from $\mathbf{F} = d\mathbf{G}/dt$, the momentum principle is as broad as Newton's second law.

The practical significance of an axiomatic theory of mechanics lies in the fact that the variables $m, t, \mathbf{F}, \mathbf{M}$, etc. have prototypes in the real world that conform closely with the preceding equations and definitions. For certain physical systems (e.g., magnetohydrodynamic systems), the angular momentum principle may be invalid, but this circumstance does not vitiate the postulate $\mathbf{M} = d\mathbf{H}/dt$; it merely restricts applications of this equation. The equation $\mathbf{M} = d\mathbf{H}/dt$ is applicable only if the internal forces exert no resultant moment. The nature of interatomic forces often is adduced as evidence that this condition is satisfied. Symmetry of the stress tensor is a closely related condition.

If $\mathbf{F} = \mathbf{M} = 0$, and if the initial conditions are $\mathbf{G}(0) = \mathbf{H}(0) = 0$, Eqs. (f) show that $\mathbf{G}(t) = \mathbf{H}(t) = 0$ for $t > 0$. This is true for any bounded system, regardless of flexibility or fluidity, provided that the equation $\mathbf{M} = d\mathbf{H}/dt$ is applicable. If the system is rigid, the conditions $\mathbf{G} = \mathbf{H} = 0$ signify that there is no motion. Thus, principles of statics issue from the momentum principles.

ON THE TEACHING OF KINEMATICS

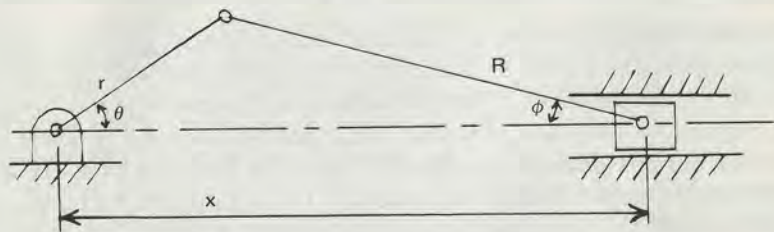
A postulational development of Newtonian mechanics seemingly provides no important generalizations, such as those which have characterized geometry.

Also, it would be too abstract for beginners. Insofar as possible, we should make education a continuous process. Continuity demands that we build on the knowledge that students already possess, and that we do not leap to new concepts and methods for which they are psychologically and educationally unprepared. Geometry is a prerequisite for mechanics, but students often are muddled in mechanics because they are poorly prepared in Euclid's theorems, algebra, trigonometry, analytic geometry, and elementary calculus. The fact that kinematics is the branch of mechanics that causes beginners the most difficulty is evidence of this deficiency. Students get much-needed drill in mathematics if they derive linear and angular velocities and accelerations of parts of mechanisms by differentiating general geometric equations with respect to t . With the burgeoning applications of computers in kinematical design, this method has become important in practice. It is the approach which serves for the derivation of the equations of relative velocity and relative acceleration that have been used widely in analyses of mechanisms. It also is the phase of kinematics that is most important for dynamics. Graphical kinematics and the associated principles may be curtailed, since they have little bearing on dynamics. For example, for the slider-crank mechanism shown in the following figure:

$$x = r \cos \theta + R \cos \phi, \quad \frac{\sin \theta}{R} = \frac{\sin \phi}{r}$$

Differentiating these equations with respect to t , and eliminating $\dot{\phi}$ and $\ddot{\phi}$, we get (with $\dot{\theta} = \omega = \text{constant}$)

$$\dot{x} = -\frac{r\omega \sin(\theta + \phi)}{\cos \phi}, \quad \ddot{x} = \frac{-r\omega^2}{\cos \phi} \left[\cos(\theta + \phi) + \frac{r \cos^2 \theta}{R \cos^2 \phi} \right]$$



Courses in dynamics usually begin with kinematics of a particle that moves on a straight axis. Accordingly, at the outset, we have the equations,

$$v = \frac{dx}{dt}, \quad a = \frac{dv}{dt} = v \frac{dv}{dx} = \frac{d^2x}{dt^2}$$

The equation $a = v dv/dx$ sometimes creates the misconception that $a = 0$ whenever $v = 0$. However, it often happens that $dv/dx \rightarrow \infty$ as $v \rightarrow 0$. For example, for the slider-crank mechanism, let $\phi \rightarrow 0$, then $v \rightarrow 0$, $dv/dx \rightarrow \infty$, and $v dv/dx \rightarrow -r\omega^2 (\pm 1 + r/R)$. The last equation represents the accelerations of the slider at the ends of the stroke.

For a rotating body, there are relationships analogous to those for rectilinear motion of a particle; namely

$$\omega = \frac{d\theta}{dt}, \quad \alpha = \frac{d\omega}{dt} = \omega \frac{d\omega}{d\theta} = \frac{d^2\theta}{dt^2}$$

Consequently, it is natural to introduce the kinematics of rectilinear motion and rotation about a fixed axis together. This approach expands the scope of problems (particularly, mechanism problems) that can be used for illustrations and exercises. Applications of the theory of rectilinear motion alone are quite limited, and the textbook problems in this area are unavoidably trite or artificial.

A topic that usually is vague in the minds of students is relative motion. It is essential to emphasize that velocities and accelerations always are measured with respect to reference frames. Even for relative motion on a straight axis, the concept of reference frames is important, as Einstein's special theory of relativity shows. Understanding of relative motion will be enhanced if teachers designate reference frames explicitly. The difference $v_2 - v_1$ of the velocities of two particles customarily is called the velocity of particle 2 relative to particle 1, but, more precisely, it is the velocity of particle 2 relative to a reference frame that translates with particle 1. The same remark applies for the difference $a_2 - a_1$ of two accelerations. One fault of Gibbs' vector analysis is that it does not clearly display the fact that a vector can be specified only by means of three scalars which are associated with some reference frame. If, for example, a surveyor goes out in the field and measures a certain vector, he must record three numbers. The earth is his reference frame. It is easy for students to understand that, if (x, y, z) are rectangular coordinates of a particle, the velocity and the acceleration of the particle *relative to that coordinate system* are represented by $(\dot{x}, \dot{y}, \dot{z})$ and $(\ddot{x}, \ddot{y}, \ddot{z})$, regardless of the motion of the reference frame to which the axes (x, y, z) are attached. By making vectors appear absolute, and by renouncing the mathematical definition of a vector as a triplet of numbers that transforms like (dx, dy, dz) , Gibbs' vector analysis sometimes tends to impede understanding. On the other hand, it appeals to the imagination, and it opens new mathematical vistas for thoughtful minds. Whether students of elementary mechanics generally have the necessary mathematical maturity to profit from symbolic vector analysis is debatable.

A serious detriment to the learning of elementary mechanics is the tendency of students to memorize special formulas. How often do they apply $v = at$ or $s = \frac{1}{2}at^2$ in cases for which the acceleration a is not constant? If special formulas did not stand out like captions in textbooks, students might be less inclined to memorize them. The fragmentation and cataloging of instructional material in textbooks tend to blur general principles, rather than to bring the mind to focus on them.

ON THE TEACHING OF DYNAMICS

The invariance of Newton's second law and of the principles of linear and angular momentum under Galilean transformations often is by-passed in elementary mechanics courses, although it is a feature of mechanics that is philosophically

important and useful in practice. For instance, in studies of progressive waves, a reference frame that travels with the waves sometimes is preferable to a so-called fixed reference frame. Also, the earth is not exactly a Galilean reference frame, and the identification of astronomical reference frames for which Newton postulated his laws to be valid is not only essential for an understanding of mechanics, but it is fundamental in celestial mechanics, space navigation, meteorology, oceanography, and other fields.

Non-Galilean reference frames frequently are useful. For instance, I recently was asked about pressure cycles in a liquid carried in a hollow reciprocating piston that is filled with liquid. In such problems, the concept of inertial force is very helpful. Also, it is valuable in vibration theory, since, for example, the differential equations for a vibrating structure can be derived from the differential equations of statical equilibrium by introduction of inertial loads. This method is particularly convenient in the theories of vibration of beams, plates, and shells.

The work that a force $\mathbf{F}$ performs during a time interval (t_0, t_1) is defined as

$$W = \int_{t_0}^{t_1} \mathbf{F} \cdot \mathbf{v} \, dt, \quad (g)$$

in which $\mathbf{v}$ is the velocity of the particle on which the force acts. Since $\mathbf{v}$ depends on the choice of the reference frame, W also depends on the choice of the reference frame. Accordingly, work is a relative quantity. This observation is consistent with the law that the total work performed on a system equals the increase of kinetic energy, for kinetic energy also depends on the reference frame.

There is a subtlety in the definition of work if the force $\mathbf{F}$ does not act continually on the same particle. In this case Eq. (g) is valid, with the understanding that $\mathbf{v}$ is the velocity of the particle on which $\mathbf{F}$ acts, and not the velocity of the point of action of $\mathbf{F}$. This distinction was emphasized by Osgood[†]. For example, if a rigid wheel rolls on a rigid track, the force $\mathbf{F}$ that the track exerts on the wheel may have a tangential component (e.g., if brakes are being applied). The velocity $\mathbf{v}$ of the particle of the wheel on which $\mathbf{F}$ acts is zero, since this particle lies at the instantaneous center. Therefore, force $\mathbf{F}$ performs no work on the wheel, despite the fact that the geometrical point of action of $\mathbf{F}$ moves along the track with the wheel. Similarly, if a grinding wheel acts on a fixed plate, the frictional force of the grinder performs no work on the plate since the plate does not move. However, the frictional force of the plate performs negative work on the grinder. The general definition of work deserves more emphasis, for there are many cases in which a force shifts from one particle of a body to another in a continuous way.

Unfortunately, the amount of important instructional material in mechanics usually is too great for the allotted class time. Consequently, teachers must weed out irrelevant and ancillary material. One topic that may be dropped is the

coefficient of restitution. This concept is an empiricism, and, unlike the coefficient of friction, it has little importance. Serious studies of impact lead to considerations of elastic or inelastic deformation and wave motion which are beyond the scope of elementary mechanics. If the coefficient of restitution is omitted, there is little need for the concept of impulse. Whether the momentum principle is written as $\mathbf{F} = d\mathbf{G}/dt$ or $\Delta\mathbf{G} = \int_{t_0}^{t_1} \mathbf{F} \, dt$ is mathematically optional, but the first form is simpler, both in form and conception. In fluid mechanics, the momentum principle is best expressed with reference to convection of momentum through a control surface; i.e., the resultant external force that acts on the fluid in a given spatial region R equals the net rate at which momentum is convected out of the region R , plus the time rate of increase of momentum of fluid in the region R . The principle of angular momentum in fluid mechanics may be stated similarly; we merely replace the words "force" and "momentum" by the phrases "moment of force" and "moment of momentum." These principles have nothing to do with special properties of fluids, and they properly belong in a general mechanics course.

UNITS OF MEASUREMENT

The want of a philosophical attitude is apparent, not only among students, but also among practicing engineers, when they confuse the concepts of weight and mass. This inability to discriminate between physical concepts that are entirely different is aggravated by the ill-chosen units called "pounds force" and "pounds mass", or "kilograms force" and "kilograms mass." Conceivably, we might adopt a unit of time called the meter (as musicians do). Then, since the meter also is a unit of length, we would have to distinguish between "meters length" and "meters time." The ambiguous use of the pound or the kilogram as a unit of mass and a unit of force slipped innocuously into thermodynamics because there is no dynamics in classical thermodynamics, except the concept of work; the equation $F = ma$ plays no role. In modern gas dynamics, where the equation $F = ma$ is involved, the ambiguity has been retained by means of the modified Newtonian equation $F = ma/g_c$. This practice further muddles the concepts of weight and mass; students are unable to decide whether gravity affects a phenomenon or not.

Hydraulicists are consistent in their units. In the United States, they have used the slug and the pound as units of mass and force, respectively. Bernoulli's equation, $p/w + v^2/2g + Z = C$, requires that w be interpreted as specific weight. Although this equation is correct, it is misleading because g is in the wrong place. For instance, flow in a horizontal conduit is unaffected by gravity, but g appears in Bernoulli's equation. Lord Rayleigh called attention to this oddity in many engineering formulas. He said, "When the question under consideration depends essentially upon gravity, the symbol g makes no appearance, but, when gravity does not enter into the question at all, g obtrudes itself conspicuously." The universal hydraulic practice of defining heads as lengths tends to promulgate this deception. It is true that head represents energy per unit weight of fluid, but the predominance of the concept of weight is itself misleading. In the equation of gas dynamics, $p/\rho + \frac{1}{2}v^2 + gz + u = C$, each term represents energy per unit

[†] W. F. Osgood, *Mechanics*, Chap. 7, Art. 7, The Macmillan Co., New York, 1937.

mass. This is a more rational way to express specific energy. The misplaced g pervades all applied mechanics, for mass m commonly is represented as W/g . This practice gives the false implication that W is invariant, and that m depends on g —a misconception that many students carry away from college into their work. It is more in accord with the nature of things to write $W = mg$, and to specify masses of objects, rather than weights. Then, if gravity has no effect on a phenomenon, g does not appear in the related equations.

The confusion is not restricted to the English system, for European engineers interpret the kilogram as a unit of force, as we see from the practice of expressing stresses in the unit kg/mm^2 . The kilogram also is used as a unit of mass, but, when Newton's law, $F = ma$, is applied, the unit of mass has been taken to be the $\text{kg sec}^2/\text{m}$. The *Système Internationale* that is now accepted by nearly all engineering societies is a supreme effort to end the ambiguity, but there is a grave danger that practitioners will persist in using the kilogram as a unit of force. Concerted efforts by textbook writers and research workers will be needed to imbue the next generation of engineers with the idea that the kilogram is a unit of mass, and that it never is a unit of force.

CONCLUDING REMARKS

Rigor will be enhanced if numerical problems are de-emphasized in favor of more weight on concepts, derivations, and interpretations of principles and equations. If algebraic symbols are specified for lengths, masses, forces, velocities, etc. in exercises, rather than numerical values, the solution to each problem becomes, in itself, a minor derivation. Such general solutions to rather special problems often are used in practice.

In a broad sense, rigor means straight thinking or good reasoning. If we accept this definition, the need for rigor in the teaching of mechanics is a truism. Perhaps the greatest detriment to straight thinking in mechanics, and parenthetically in other branches of physics, is the want of a philosophical attitude. Habits of contemplation which are essential for understanding of mathematics and physics are not cultivated in engineering colleges more than in the past. Possibly teachers can do little to develop them, but educational experiments in this direction are rare. Students in engineering seldom are required to master deductive proofs, yet real understanding of fundamentals comes only from such mastery. Nothing is more practical than a good theory, and the key to proper applications of the theory is comprehension of the development of the theory.

Demonstrations to Aid Teaching of Mechanical Vibrations

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Students beginning the study of vibrations can be helped in achieving an early grounding in the subject by a few simple demonstrations. The object of these demonstrations is to display in a systematic manner the nature of some common vibrating systems in an effort to show the basic similarities in their behavior. The demonstrations presented are simple enough to be appreciated by beginning students and take little time to perform. Also, they are inexpensive and easy to make.

The usual approach to the teaching of mechanical vibrations is to develop a fairly complete body of theory for single degree of freedom systems before proceeding on to the next more physically and mathematically complex system and the development of a similar body of theory concerning it. This approach is reasonable and also convenient for the mathematical development of the subject, but with its concentration on particular systems, one at a time, it emphasizes differences between systems rather than similarities. As a result, the aspects of similarity connecting different systems and some coherence in the subject matter tends to be lost.

It is possible, however, to develop some awareness of this underlying unity during the first few weeks of an introductory course with the aid of simple demonstrations such as the ones presented here. These demonstrations are inexpensive to make and easy to use. Through their use, basic characteristics of a system's response become audibly or visually apparent, some of which would require considerable time and effort to demonstrate mathematically with somewhat less impact. Taken collectively, these demonstrations attempt to give insight into the dynamic response of a broad class of systems to harmonic or near harmonic excitation and to illustrate their common aspects.

Vibrating systems are classified by whether the system is linear or nonlinear, also by the type of damping present and the degree to which the system is damped and, finally, by the number of coordinates needed to describe the system's con-

figuration, usually referred to as degrees of freedom. Also, the excitation causing the vibration can be initial values of velocity and displacement or it can be a forcing function of one form or another, the resulting vibrations being called free or forced respectively.

In terms of the above classifications, the systems being considered here are linear. Though they may contain damping, the influence of damping on the system's response is not significant except in the vicinity of resonance where the principal effect is to limit displacements. The degrees of freedom will range over the total spectrum from one to an infinite number in the case of a continuous system. The excitations being considered are forced and though not necessarily harmonic, they are at a minimum periodic. The following demonstrations are intended to be examples of systems and responses taken from the class defined above.

Starting with the forced vibration of a continuous system, the response of this type of system to a forcing function can be demonstrated using the mechanism from a child's music box. When the mechanism is physically removed from the music box container and then played, the sound it produces is barely audible. However, when placed in contact with a window pane, a plastic cup, the side of a cardboard box or any other object which can be dynamically excited and which also is a good radiator of sound, the melody being played is suddenly amplified many times and, of course, the melody is clearly the same in each case with perhaps some changes in tone but not in pitch. Since the music box mechanism is a forcing function which causes the object it is placed in contact with to vibrate, it is clear that in forced vibration of continuous systems, the system vibrates at the frequency (or frequencies) of the forcing function. The same relationship, of course, exists between the forcing function and response frequencies for multidegree and single degree of freedom systems and constitutes a common characteristic of the response of these various systems.

Moving to forced vibration of a multidegree of freedom system, another aspect of the forced vibration phenomenon which was not apparent in the previous demonstration will become apparent here, that is the dependence of the vibration amplitude on the frequency of the forcing function. This becomes most apparent when the forcing function is operating at a normal mode frequency.

The apparatus for this demonstration is shown in Fig. 1. It consists of three glass beads on a fine wire which constitutes the vibrating element of the system. The wire is held taut between two supports. One of these supports is a piece of a hack-saw blade which constitutes a cantilever beam and is attached to a movable block at its fixed end. The position of this movable block and the resulting curvature produced in the hack-saw blade is used to adjust the tension in the wire. Mounted at the mid-section of the hack-saw blade is a miniature dc motor which operates on either 1.5 or 3.0 volts. It is the variety of motor that can be purchased in a hobby shop for approximately \$1.50. A small eccentric mass is attached to the shaft of the motor and it is this eccentric mass when rotating which provides the excitation to the wire and beads. The beads are fastened to the wire so that the center bead is approximately at the mid-point while the other two are symmetrically placed to each side of center. Though the motor



Fig. 1. The apparatus.

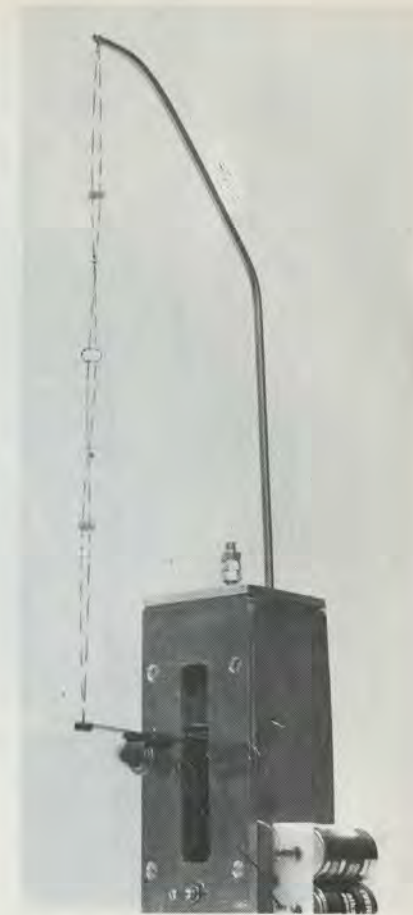


Fig. 2. Third mode.

has a potentiometer in series with it, the motor is run at maximum speed in this demonstration.

To perform the demonstration, the motor is permitted to run while the tension in the wire is slowly increased from the loose condition. The wire may jump around initially but eventually a third normal mode vibration will appear as is shown in Fig. 2. Increasing the tension beyond this point will cause the third mode to vanish and the amplitude to diminish. Continuing to increase the tension will eventually produce a second normal mode followed by a low amplitude vibration and finally replaced by a large amplitude first mode at a fairly high tension setting. These normal modes can be seen in Figs. 3 and 4.

This result clearly demonstrates the phenomenon of normal modes as well as the frequency dependence of amplitude. As the tension in the wire changes the characteristics of the system change and so does the response of the system to a fixed excitation frequency. This approach of changing the system's char-

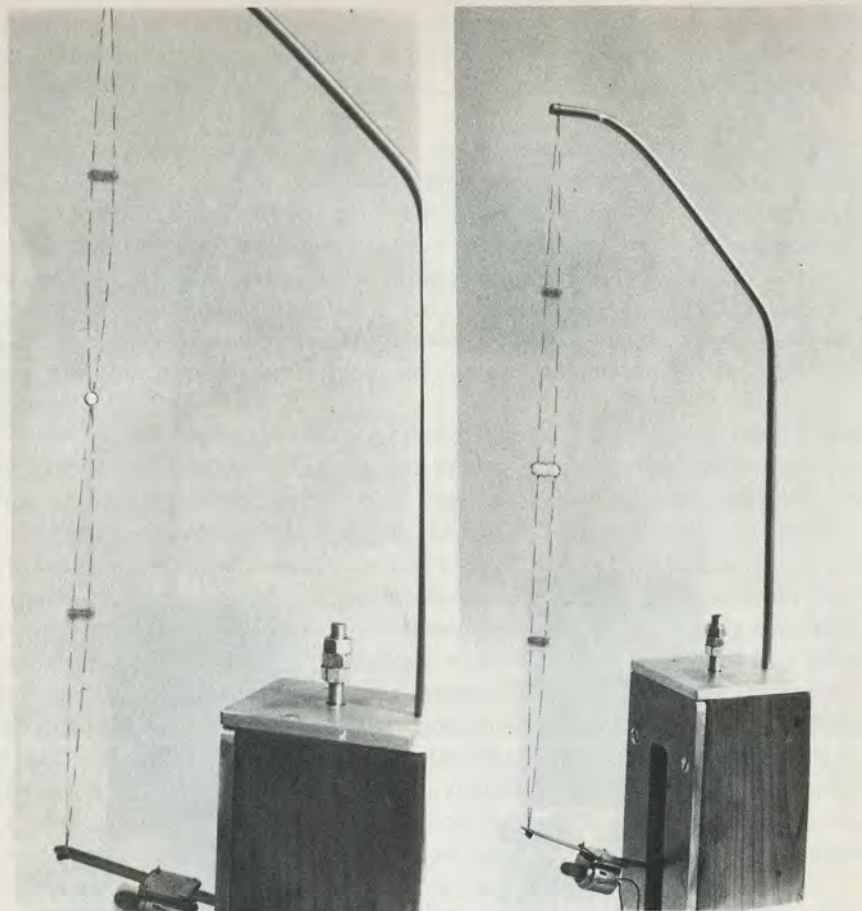


Fig. 3. Second mode.

Fig. 4. First mode.

acteristics rather than the excitation frequency was used to allow the apparatus to be simple and low cost and yet demonstrate three normal modes. Holding the wire vertically rather than horizontally has been found to improve the performance of the apparatus. Again, though the demonstration was for a multidegree of freedom system, the observation made is equally true for continuous or single degree of freedom systems.

Though the dimensions of the system are not critical, the apparatus as shown in Fig. 1 uses a .010 in. diameter aluminum wire which is 18 in. long. The ellipsoidal glass beads are approximately $.2 \times .25$ in. The piece of through-hardened hack-saw blade measures 5 in. between its block support and the point of attaching the wire. The motor is a #15 manufactured by Mabuchi and the manufacturer indicates a speed of 7150 RPM presumably at the maximum voltage of 3 volts which can be supplied by two D size batteries. The motor speed can be lowered by reducing the motor voltage.

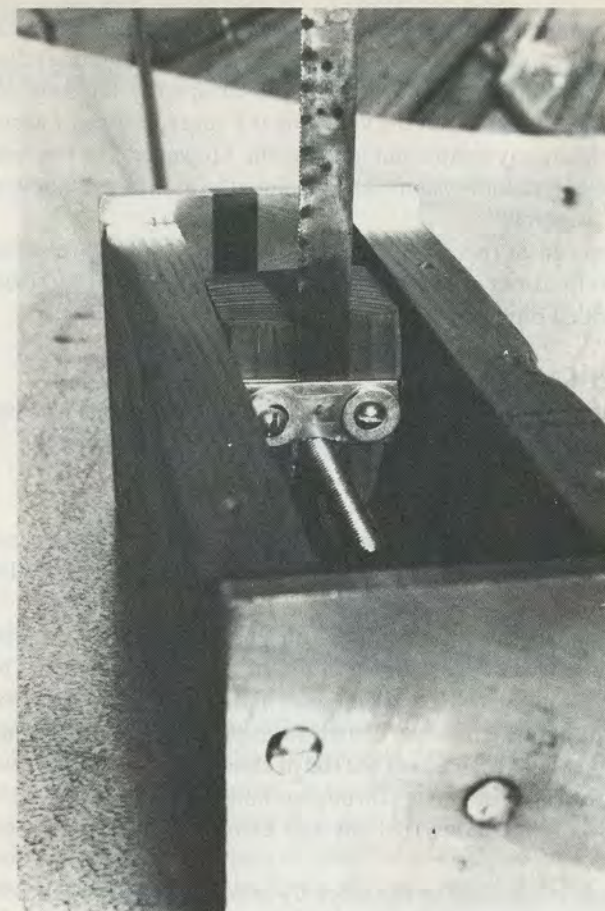


Fig. 5. Mechanism for changing the wire tension.

The apparatus described above can also be used to demonstrate a one degree of freedom forced vibration. To do this, the wire is removed from the hack-saw blade. The combination of hack-saw blade and motor approximates a single degree of freedom system with the motor mass being the principal mass of the system. Varying the motor voltage with a small potentiometer can produce a speed range which goes from zero to above resonance. When the motor is operated at various speeds in this range, the dependence of amplitude on the excitation frequency is evident, especially at resonance. It is also evident that the frequency of the forced vibration increases with the excitation frequency, however, it is not obvious that they are the same.

These demonstrations illustrate certain characteristics of the forced vibration of mechanical systems in the class indicated. They are:

1. Systems excited by a harmonic or near harmonic forcing function respond at the frequency of the forcing function.

2. The amplitude of vibration is dependent on the frequency of the forcing function and large amplitude vibrations occur at normal mode frequencies.

If the free vibration of undamped or lightly damped systems are considered, the unifying characteristic that the vibration is a superposition of normal modes is not evident from any simple demonstration. However, the free vibration of a single degree of freedom system can be pointed to as, at least, not violating the superposition principle.

Most students enter their first vibrations course with little sense experience of mechanical vibrations and so demonstrations like the ones described can help provide this added dimension.

ACKNOWLEDGMENT

The author wishes to gratefully acknowledge Antonio Ornelas who contributed to the design and construction of the apparatus described here.

APPENDIX

In Fig. 5, the vibration apparatus is shown with the cover plate removed permitting the movable block and attachment of the hack-saw blade to be viewed.

The movable block is maintained in position as well as moved to a new position by means of the threaded rod shown in the figure. Rotation of the rod causes the block to move along the axis of the rod. The rod is free to rotate in the end plates which support it, and axial constraint is provided by tightening two nuts against each other near each end of the rod in close proximity to the inside surface of the end plates. The rod passes through a hole in the block where it engages a nut embedded immediately behind and below the attachment of the saw blade.

The saw blade is attached to the block by gripping its lower end between two small pieces of steel flat stock. The gripping is done with two machine screws, the heads of which are visible in the figure. The screws pass through holes in the block and are tightened with nuts on the opposite side.

MECHAIDS—

A Self-Paced Remedial Learning Tool

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Helping students who encounter difficulty is a concern of every institution of higher learning. Engineering schools probably have a greater need for and expend more effort in remedial instruction than do most others. At the United States Military Academy the need is perhaps greater still because a number of engineering courses are required of all cadets, many of whom have interests and aptitudes focused in other areas. For example, all cadets take courses in statics and dynamics and thermodynamics. The cadets, to be sure, are carefully screened for overall academic ability before admission. Most are able to handle the general curriculum, which consists largely of specified courses across a broad spectrum of subject areas. Some, however, invariably run into difficulty.

West Point uses the same time-tested methods for giving special help to students as are employed at other good schools. Instructor counseling attempts to prevent students from getting into trouble in the first place. Instructors are available outside of class, not only at specified office hours, but at any time, including by telephone at home. Additional instruction is scheduled and conducted daily in the late afternoon. Cadets who wish to attend are excused from military duties for this purpose. Many cadets, however, have difficulty in finding time for additional instruction or counseling because of athletic practices, being in the hospital, or other various reasons. Some cadets need help beyond the scheduled additional instruction yet may be reluctant to ask for more help.

In 1971, the Department of Mechanics realized the need for a method of remedial instruction that could be tailored more to the cadets' busy schedule and began experimenting with a means of accomplishing this. We wanted a self-paced method, so that the students could use it at times of their own choosing and at their own individual speeds. We wanted it to be attractive to them so they would use it. We wanted it to be simple so that we could make a lot of them and would not be deterred from revising them when necessary. Although we were willing to commit a good share of our resources to the effort, we naturally pre-

ferred that the device be inexpensive; and above all, it had to give students using it effective help.

The desire for simplicity and flexibility led us to reject several approaches that called for specialized audio-visual equipment or computer-driven displays. The approach eventually adopted was called a "MECHAID," a name whose derivation should be evident. We felt that any effective remedial tool should include a review of all applicable theory and a heavy emphasis on problem-solving techniques and example-problem solutions. For simplicity and portability, we wanted to stay away from television or other cathode-ray display devices. We looked at what other possible media devices the students were used to and that they would feel comfortable with.

A cassette tape playable in an ordinary portable tape recorder seemed the ideal solution and was adopted. Yet audio instruction was not enough since all good teachers realize that audio reception must be supplemented by visual display to be really effective. So we combined the cassette tape with an illustrated text in a notebook. The tape talks a student through the instructional material in the notebook, which is designed to be appealing, yet concise and helpful. The written material is presented in outline form as graphically as possible. Appropriately for remedial instruction, the material is limited to the bare essentials of what the student is expected to understand and know how to do. Worked example problems are included as well as practice problems for the student with solutions. The tape leads the student through the theory, problem-solving steps, and problem solutions amplifying the written material and diagrams. The written material is in large type, and the figures are carefully and clearly drawn. Packaging is in a large three-ring binder with a colorfully designed cover. In the rear cover of the binder are sheets for student comments, an envelope with the cassette tape, and a library card. The student may use the MECHAID in either the main or department library (tape recorders are provided) or he may check out the MECHAID from the department library in the same way as a book. Tape recorders may also be checked out if the student does not possess one of his own.

We have built up a MECHAID library for the four core or fundamental courses that are taught in the department: Engineering Mechanics, Thermodynamics, Fluid Mechanics, and Thermo-Fluid Dynamics. Annex A contains a list of the MECHAIDS that are available for each of these courses. Annex B contains extracts from a sample script and notebook pages for one of the MECHAIDS.

In use, a combination of written material with a cassette tape has many desirable features. The student can stop, rewind, and go over again any portion of the tape desired. The tape can be stopped while problems are being worked. Revisions of the taped script and the written material are relatively simple; our experience is that we revise or completely do over most MECHAIDS every two or three years. A major revision effort was necessary three years ago when we converted our Thermodynamics course to metric units; it was nevertheless possible to accomplish the revision in a timely fashion within our own resources.

While the MECHAIDS were designed for remedial instruction, we have found that the students use them for other purposes as well. If a student has missed some classes, the MECHAID is a handy way to catch up. Instructors check them out and take them to students who are in the hospital. Many students use them to review for examinations. The reader should note, however, that the MECHAIDS are not intended nor designed to be the primary form of instruction; we do not use them now nor do we plan to use them in the future to replace the instructor in the classroom.

In 1977 we began experimenting with MECHAIDS on television tape cassettes. We thought that the familiarity with television medium might make the MECHAIDS more attractive to cadets and thus generate more use. We made the TV MECHAIDS in two different styles. The first was an almost exact copy of the audio version using essentially the same figures and script. The instructor, except for introductory and summary comments, is a disembodied voice. The other style is an approximation of a televised class. The instructor presents the material much as would be done in the classroom but with a carefully rehearsed script and predrawn figures to condense the time. Planning is easier for the first style, but it is rather dry; the second is more dynamic and appears to be more appealing to the student.

There are certain drawbacks to the TV MECHAID as compared to the earlier version, however. If the TV tape is stopped for working a problem, the picture, and therefore the figure, disappears. They are not nearly as portable as the audio tape version, and the availability of player units has not permitted us to distribute the tapes in an optimal way and has prevented any "take-home" loan program. They are also much more difficult to revise and are more expensive.

Some words about cost may be appropriate. The material costs for our standard MECHAID are quite minimal. The three ring binder costs about \$2.50, the cassette tape is less than \$1.00, and the portable tape recorders cost somewhere around \$40 to \$50 each. The number of copies of each MECHAID varies with the course enrollment, going from nine copies of each MECHAID for our heavy enrollment courses (600 students per semester) to five copies for courses with enrollments of 200 students per semester. The TV MECHAIDS are, of course, considerably more expensive. The TV cassette itself costs about \$25 while the carrell which includes a playback unit has a cost of almost \$2000 each. We have made three copies of each TV MECHAID; two are maintained with the carrells in the Audio-Visual Room of the main library, and one is maintained with the carrells that are located in the hospital.

Probably more important than the material cost are the hours of valuable time required to prepare and revise the MECHAIDS. For the standard MECHAIDS (the audio version), preparing a new one takes from 20 to 40 hours of instructor time plus about as much time in secretarial support. Revising one requires from five to 20 hours, depending on the extent of the revision. Preparing a TV MECHAID is a more extensive effort. Those we have made require about 80 hours of instructor time plus about 100 man-hours of graphics and television studio support. We have not revised any of the TV MECHAIDS yet, but believe the revision would be nearly as large a task as initial preparation.

End of course surveys shows that one-third to one-half the students in our courses have used the audio MECHAIDS. Use of the TV MECHAIDS has been very much less, although we're not sure whether the cause of this lesser use is a lower utility of the TV MECHAID to the student or their reduced accessibility. Of those students who have used the MECHAIDS, nearly all report that they were helped. We do have some difficulty getting the students to use the MECHAIDS the first time, thereafter the MECHAIDS sell themselves.

The MECHAID is a relatively inexpensive remedial instruction device that has proven very effective for what it was designed to do. It is a useful addition to our arsenal of instructional tools.

ANNEX A. MECHAID List

- I. Engineering Mechanics
 - A. Forces & Moments*
 - B. 2-D Equilibrium*
 - C. 3-D Equilibrium*
 - D. Friction
 - E. Truss Analysis*
 - F. Frame Analysis*
 - G. Internal Forces & Stress*
 - H. Normal Strain and Statically Indeterminant Structures*
 - I. Shear & Moment Diagrams*
 - J. Instantaneous Centers
 - K. Relative Acceleration Equations
 - L. Force/Acceleration
 - M. Impulse-Momentum
 - N. Central Impact
 - O. Work and Energy
 - P. 3-D Kinematics
 - Q. Vibrations
 - R. Simple Tension Test (TV version only)
- II. Thermodynamics
 - A. Fundamental Thermodynamic Concepts
 - B. Steam Tables & Mollier Diagram
 - C. 1st Law for a System (H_2O) and Work for a System
 - D. 1st Law for a Control Volume (H_2O)
 - E. 2d Law: Heat Engines, Refrigerators/Heat Pumps, and the Carnot Cycle
 - F. 2d Law for System
 - G. 2d Law for Control Volume

- H. Isentropic Efficiency
- I. Steam Power Cycles & Pump Work
- J. Vapor Compression Refrigeration Cycle
- K. Ideal Gas Relations
- L. Applications of Ideal Gas Relations
- M. Combustion
- N. Air-Water Mixtures
- O. Mixtures
- P. Availability and Reversibility

III. Fluid Mechanics

- A. Absolute and Gage Pressure—Manometry
- B. Forces on Plane Submerged Surfaces
- C. Forces on Curved Submerged Surfaces
- D. Conservation of Mass
- E. Conservation of Energy
- F. Momentum Principle
- G. Similitude and Modeling
- H. Loss Calculation in Pipe Flow Problems
- I. Converging-Diverging Nozzles*

IV. Thermo-Fluid Dynamics

- A. Fundamental Thermofluid Concepts
- B. The Vapor Dome and the Ideal Gas
- C. 1st Law for a System and Work for a System
- D. Conservation of Mass and Energy for Steady-State, Steady-Flow
- E. The 2nd Law of Thermodynamics: Heat Engines, Refrigerators/Heat Pumps and the Carnot Cycle
- F. The 2nd Law for a System. Entropy Change for an Ideal Gas. Isentropic Relations
- G. The 2nd Law for Steady-State, Steady-Flow
- H. Isentropic Efficiency
- I. Applications of Ideal Gases
- J. Methods of Cycle Analysis
- K. Vapor Compression Refrigeration Cycle
- L. Air-Vapor Mixtures
- M. Conservation of Mass & Bernoulli's Principle
- N. Momentum Principle
- O. Compressible Flow Through Converging Nozzles
- P. Compressible Flow Through Converging-Diverging Nozzles and Normal Shock Waves
- Q. Aerodynamics

* TV as well as audio MECHAID

* TV as well as audio MECHAID

ANNEX B. Sample MECHAID

I. Sample Script Extract From MECHAID on Forces & Moments (Scalar Approach)

This tape is designed for use with the MECHAID entitled Forces & Moments Scalar Approach. We live in a three-dimensional world, however, many of the things we see around us can be modeled using two-dimensional models. The truck on page 1 is an example of this. Even though we know this to be a three-dimensional figure, we can model it successfully with a two-dimensional free body diagram. In two dimensions, the scalar approach to forces and moments tends to be the easiest to use. A force, as you know from your physics instruction, is a push or pull. It is the action of one acting on another. All forces have three characteristics: magnitude, direction, and point of application. The magnitude of a force measured in pounds, thousands of pounds, or newtons, tells us how strong the force is. The direction and sense tell us which way the force acts. In the case of our truck trailer, does each force tend to pull the trailer up or down the plane? By knowing the point of application of a force, we can tell whether the force will cause a body to move with only translation or to both translate and rotate. We will deal with this tendency to cause rotation when we take up moments. In two dimensions, we want to be able to add forces together. Since the force is a vector quantity having magnitude, direction, and point of application, we cannot simply add the magnitudes of two forces together. We must first break each force into components and then add components which act in the same direction. Take the 50 pound force shown on page 2 as an example. We will break this force into components parallel to the x and y axes system shown. We can see that the 50 pound force has a slope of 4 on 3. We always express slope as the rise over the run. In this case, a 4 on 3 slope. The x component of the 50 pound force is equal to the force itself times the cosine of the angle between the force and the x axis. We know that this cosine would be the 3 side of the slope triangle divided by the 5 side. Likewise, the y component would be the magnitude of the force times the sine of the angle or $\frac{4}{5}$ of 50. This gives us the x and y components of the 50 pound force. Our answer must show magnitude, direction, and point of application; for example, 30 pounds to the right through point A. We can also show this force in vector form as you see on the bottom of the page using the unit vectors $\mathbf{i}$ and $\mathbf{j}$ to denote the direction of the components of the force. We must say through A to show the point of application for the force in this form. Turn to page 3. Here are two example problems which you should work. Break the forces shown into components parallel to the x and y axis system. Assume the x is horizontal positive to the right and y vertical positive upward. Turn off the tape recorder. Break these forces into components and check your answers against the solution given on page 4. On page 4 you will see that we have broken the force P 65 pound force into components parallel to the x and y coordinate directions: the $\frac{12}{13}$ component in the positive x direction, the $\frac{5}{13}$ component in the negative y direction. Notice once again that each of our answers shows magnitude, direction, and point of application. For the force Q in problem B,

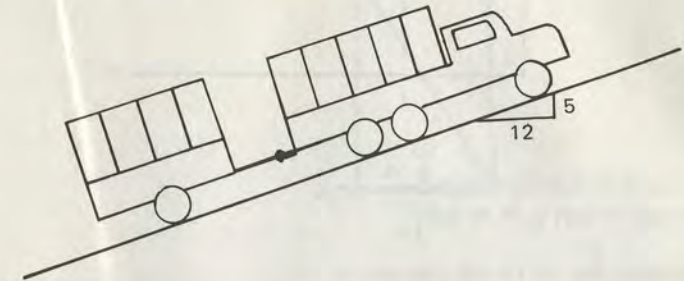
we see that the x component is equal to 100 pounds times the cosine of 60 degrees, the angle between the x axis and the 100 pound force. This gives us 50 pounds in the negative x direction which we show by an arrow to the left. Likewise, the y component is equal to 100 pounds times the sine of 60 degrees or 100 pounds times the cosine of 30 degrees which would be the angle between the force and the y axis. Again, we see magnitude, direction, and point of application in our answer. If a force acts either horizontally or vertically, we can show its direction using just an arrow in the appropriate direction. If, however, our answer should contain a force which acted in some other direction, we must show either a slope or an angle in our answer to properly denote the direction of that force. Turn to page 5. We have now practiced breaking a force into components parallel to an x and y axis. Sometimes it is more convenient to break the force into its components which are parallel and perpendicular to a given slope. An example of this was on page 1 where we had the free body diagram of the truck trailer. We might want to break the forces on that diagram into components parallel and perpendicular to the 5 on 12 slope on which the trailer rests. On page 5 we see a table attached to a collar which slides on a rod that has a 3 on 4 slope. Notice that the 75 newton force is already in the x direction. If, however, we can find the components of this force along the sloping rod and perpendicular to the sloping rod, we can find that part of the force which is tending to pull the collar up the rod at that part of the force which is causing the collar to bear against the rod. The resultant force F is the hypotenuse of two similar 3-4-5 triangles as shown in the picture. Prove to yourself that the sides of each of these triangles have been correctly labeled. You may also think of this force F as a diagonal of a rectangle with sides 4 and 3. Now using the same procedure that we used in breaking a force into x and y components, we can see that the component of the force F perpendicular to the plane is the $\frac{3}{5}$ component while a component parallel to the plane is the $\frac{4}{5}$ component. Since this type of problem appears often in our Mechanics course, it is convenient to find an easy way to remember the rule for finding the parallel and perpendicular components. Notice that the 75 newton force is parallel to the 4 side of the slope triangle and perpendicular to the 3 side of the slope triangle. We can then identify the parallel component of the force F as the $\frac{4}{5}$ component and the perpendicular component of the force F as the $\frac{3}{5}$ component. Let us state this rule once again. The perpendicular component method states that the perpendicular component of a force F is related to the side of the slope triangle to which the force F is itself perpendicular. Once we find the perpendicular component, the parallel component, of course, is easily found. Turn to page 7. Let us try a sample problem to be sure that we understand how to apply the perpendicular component method. The 150 pound cadet is standing on the ramp leading from new south area. The ramp was built conveniently on a 3 on 4 slope. To find the components of his weight parallel and perpendicular to the 3 on 4 slope, we would use the perpendicular component method. Notice that the 150 point force is perpendicular to the 4 side of the slope triangle. We know, therefore, by geometry that the component of the 150 point force perpendicular to the slope is the $\frac{4}{5}$ component or $\frac{4}{5}$ of W . Similarly, the 150 pound force is parallel to the 3 side of the slope triangle. Hence, we know

that the parallel component of the cadet's weight will be $\frac{3}{5}$ of his total weight. Our answers depict these results. Notice that since these components are neither horizontal nor vertical, slope triangles are required to properly show their direction. Notice also that a vector that is perpendicular to a plane has a slope which is a reciprocal of the slope of the plane. In this case, the perpendicular component of the weight has a 4 on 3 slope since it is perpendicular to a plane with a 3 on 4 slope. This can be calculated using geometry for it is an easy relationship to remember. Once again, the statement of the perpendicular component method. The perpendicular component of a force is related to the side of the slope triangle to which the force itself is perpendicular. Although this may seem like a simple rule to remember, it is very important. Remember, we want to break forces into components so that we may add these components together. The sample problem on page 8 demonstrates finding a resultant force. A resultant is a force which has the same effect on a body as the force system it replaces. In the sample problem there are four forces concurrent at point C. In order to add forces together, they must be concurrent. This means all of the lines of action must intersect the one point. To add these forces together, you break each force into x and y components. We could then add each of these components together. We must first establish a sign convention to tell us where the positive x and y directions lie. To keep our numbers straight, since we will have many numbers, we set up a table which lists in its columns the forces, the x and y components of each of the forces. The table is not essential but generally helps cadets with their bookkeeping until they have gained more familiarity with this type of problem. Verify for yourself that each of the components shown in the table is, in fact, a component of the force that you see in the diagram at the top of page 8. You can turn off the tape recorder while you do this. Once we have found the components of each of the forces, we can add these components together. Our sign convention tells us the sign of each component. Add each column to get the result of the force. There are three ways to correctly portray your answer. We can show the magnitude, direction, and point of application of each component; we can show the total resultant force R in vector form using I and J unit vectors to denote its direction; or we can show the magnitude, direction, and point of application of the total resultant force R. We find that magnitude by taking the square root of the sum of the square of the two components. If you are asked in a problem to find the resultant force, any of these three answer representations will be acceptable. However, you must give the magnitude of the resultant force if that answer is requested. Turn to page 9. On page 9 is a practice problem that you can complete for yourself to test your proficiency in finding resultant forces. Four forces are applied to the piton imbedded in the overhanging rock face. Determine the components of the resultant of these forces both in the horizontal and vertical directions and in directions parallel and perpendicular to the rock face. Turn off the tape recorder while you complete this problem. We will then discuss the solution together.

II. Extract from MECHAID notebook on Forces & Moments (Scalar Approach)

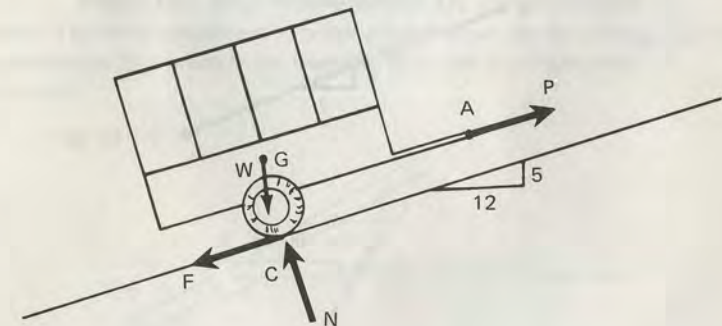
FORCE

The action of one body on another

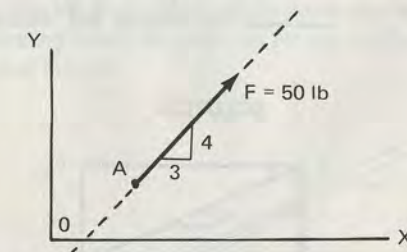


Forces are characterized by:

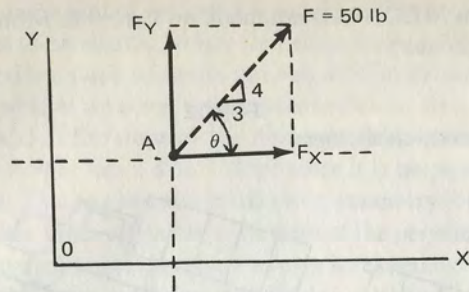
- Magnitude (pounds, kips, newtons, etc.)
- Direction (slope or angle)
- Point of application



FORCES IN TWO DIMENSIONS



Scalar form: $F = 50 \text{ lbs}$ A 
Break the force F into its components parallel to the X and Y axes.



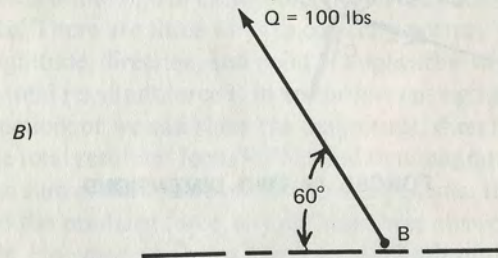
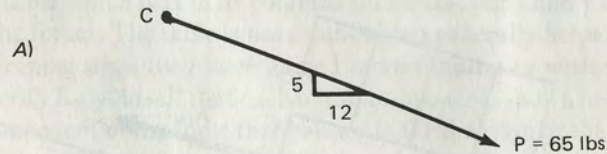
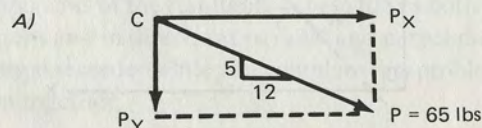
$$F_x = F \cos \theta = (50) \frac{3}{5} = 30 \text{ lbs}$$

$$F_y = F \sin \theta = (50) \frac{4}{5} = 40 \text{ lbs}$$

or

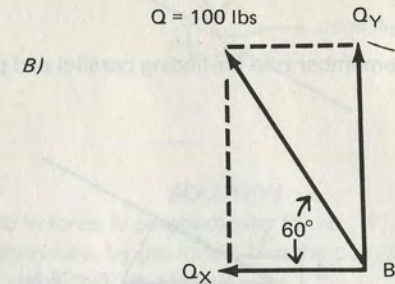
Vector form: $F = 30 \mathbf{i} + 40 \mathbf{j}$ lbs thru A**PROBLEM**

What are the X and Y components of these forces?

**SOLUTION**

$$P_x = \frac{12}{13} (65) = 60 \text{ lbs}$$

$$P_y = \frac{5}{13} (65) = 25 \text{ lbs}$$



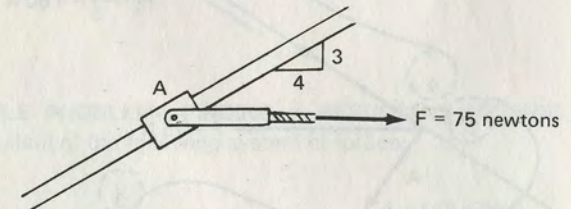
$$Q_x = 100 \cos 60^\circ = 50 \text{ lbs}$$

$$Q_y = 100 \sin 60^\circ = 86.6 \text{ lbs}$$

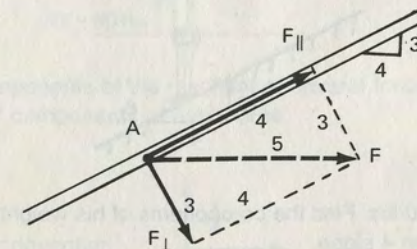
PARALLEL AND PERPENDICULAR COMPONENTS

Sometimes it is more convenient to break a force down into its components parallel and perpendicular to a given slope than into its X and Y components.

For example:



Notice that the 75 N force is already in the X direction; but if we can find the components of this force along the sloping rod and perpendicular to it we can find the part of the force which is tending to pull the collar up the rod and the part which is causing the collar to bear against the rod

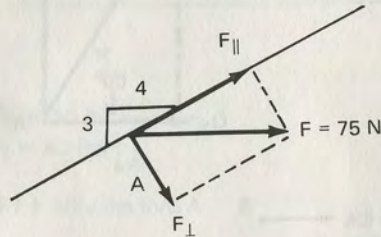


The resultant, F , is the hypotenuse of two similar (3-4-5) triangles as shown.

Prove to yourself that the sides of each of the triangles have been correctly labeled.

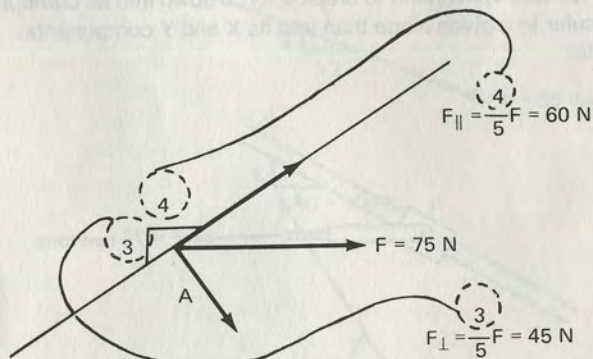
Notice that $F_{\perp} = \frac{3}{5} F$
and $F_{\parallel} = \frac{4}{5} F$

A quick and easy-to-remember rule for finding parallel and perpendicular components

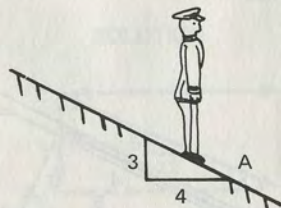


Notice that the 75 newton force is *parallel* to the "4" side of the slope diagram and *perpendicular* to the "3" side of the slope diagram.

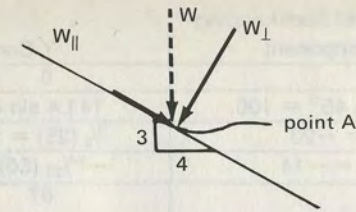
We can then identify the *parallel* component, $F_{\parallel}$, as the " $\frac{4}{5}$ " component and the *perpendicular* component, $F_{\perp}$, as the " $\frac{3}{5}$ " component.



SAMPLE PROBLEM



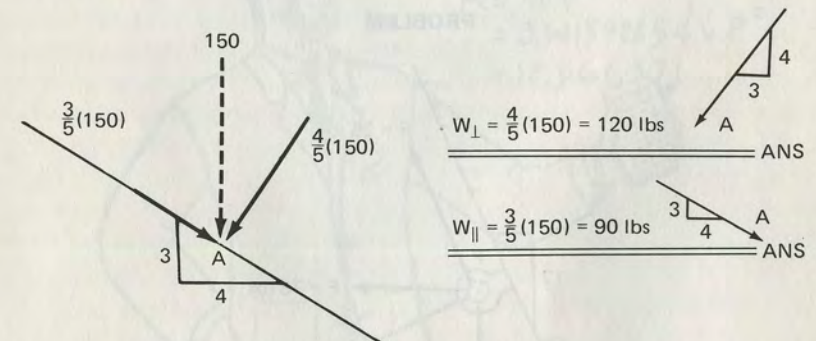
The cadet weighs 150 lbs. Find the components of his weight parallel and perpendicular to the 3 on 4 slope.



SOLUTION

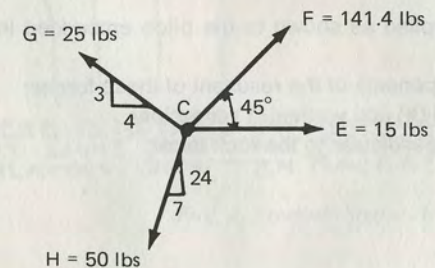
Notice that the 150 lb force is perpendicular to the "4" side of the slope diagram. We know, therefore, by geometry, that the component of 150 lb force perpendicular to the slope ($W_{\perp}$) is " $\frac{4}{5}$ " W .

Similarly, the 150 lb force is parallel to the "3" side of the slope diagram; hence $W_{\parallel} = \frac{3}{5} W$.



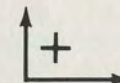
SAMPLE PROBLEM—FINDING A RESULTANT (ADDING FORCES)

Find the resultant of the following system of forces:



The X and Y components of the resultant of several forces are respectively the sum of the X and Y components of each force.

Establish a sign convention



Set up a table for ease of bookkeeping

Force	X Component	Y Component
E	15	0
F	$141.4 \cos 45^\circ = 100$	$141.4 \sin 45^\circ = 100$
G	$-\frac{4}{5}(25) = -20$	$\frac{3}{5}(25) = 15$
H	$-\frac{7}{25}(50) = -14$	$-\frac{24}{25}(50) = -48$
Resultant Σ	81	67

$$R_x = 81 \text{ lbs } \xrightarrow{C} \text{ANS}$$

$$R_y = 67 \text{ lbs } \uparrow^C \text{ANS}$$

or

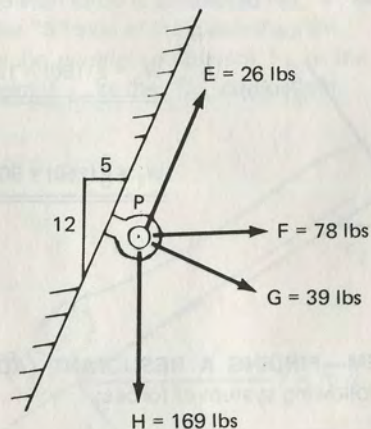
$$R = 81 + 67 \text{ lbs thru } C \text{ANS}$$

or

$$R = \sqrt{(81)^2 + (67)^2}$$

$$= 105.1 \text{ lbs } \nearrow \begin{matrix} 67 \\ 81 \end{matrix} \text{ANS}$$

PROBLEM

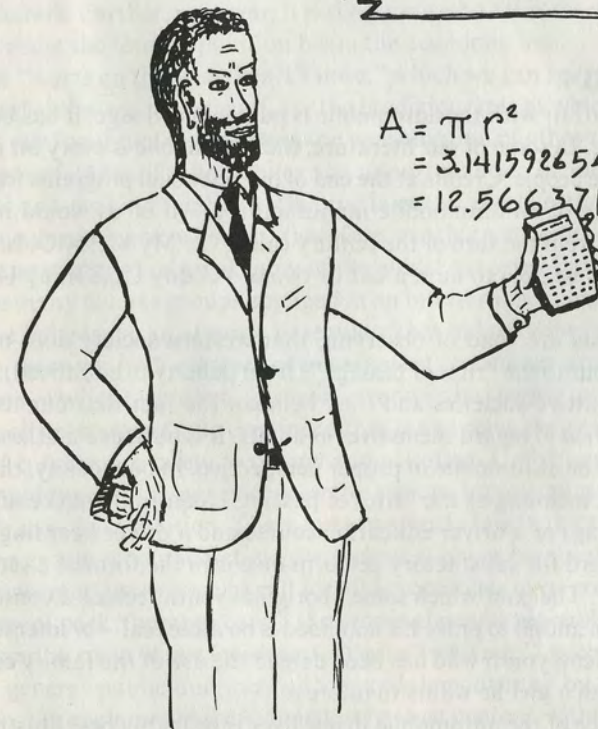


Four forces are applied as shown to the piton embedded in an overhung rock face.

Determine the components of the resultant of these forces:

- In the horizontal (X) and vertical (Y) directions.
- Parallel and perpendicular to the rock face.

ALWAYS INSIST UPON
APPROPRIATE
ACCURACY!



$$A = \pi r^2$$

$$= 3.141592654 \times 2^2$$

$$= 12.566371$$

THERE IS NOTHING UNREASONABLE
ABOUT EIGHT SIGNIFICANT FIGURES. YOUR
CALCULATORS SHOW TEN PLACES!

Prof. Z. Freebody Snafu—Elmer L. Munger

The Mechanics of Vehicular Safety

RICHARD P. McNITT* and JAMES H. SWORD†

INTRODUCTION

America's love affair with the automobile is public knowledge; it has been told in story and song. In some of our literature, the automobile is every bit as much a character as the people. Credits at the end of our television programs frequently include the name of an automobile manufacturer. All of us would instantly recognize a tune from the turn of the century called "In My Merry Oldsmobile"; some of us might be able to hum a bar or two of "Giddy Up, Giddy Up, 409" from the 60's.

Anthropologists are fond of observing that western society does not have anything analogous to the "rites of passage" (from puberty to adulthood) of some of the more primitive societies and they bemoan the fact that our teenagers cannot be sure when to regard themselves as adults. It is obvious that these people have not placed the automobile in proper perspective. In our society, the words take on a double meaning as the "rites of passing" require the successful completion (or passing) of a driver education course and a driver licensing examination. The reward for satisfactory performance is in the form of a set of keys to the family car. The pain which some aboriginal youth feels as a consequence of being tied to an anthill to prove his manhood is no more real—or intense—than that of an American youth who has been denied the use of the family car when he has a date with a girl he wants to impress.

The importance of the automobile in our lives is probably best illustrated by two facts. First, for many American families, there is more money spent in acquiring and maintaining one or more automobiles than for any other single controllable item in the budget—including food and shelter. Second, a large part of crime attributed to youthful offenders is motor vehicle related. The illegal acts range from stealing cars for so-called "joyrides" to committing robbery and worse in order to achieve the status that comes with the ownership of "a set of wheels." We are, for better or worse, married to the automobile. For most of

us it is a bigamous relationship, to be sure, but one accepted by the society in which we live.

As in all great love affairs, this one has its tragic aspects. Chief among these is the killing and maiming of tens upon tens of thousands of people in more than sixteen million accidents each year. To put the tragedy into proper perspective, note that approximately 45,000 people are killed annually in vehicle-related accidents in the United States. This is about the same as the number of Americans who lost their lives in the entire Vietnam war. (Perhaps the real tragedy is that we accept these appalling statistics without a murmur; that we do not have the public outcry of protest which accompanied our involvement in that war.) In addition, the yearly economic loss in these accidents is a staggering 40 to 45 billion dollars. Further, as in war, it is the young who are most often the physical victims while the total population bears the economic loss.

Other "warts on the sweetheart's nose," which we can recognize when some of our early infatuation wears off, are the prodigious rate at which the automobile devours our fossil fuel reserves and the consumption of other natural resources in the manufacture of automobiles and appurtenances, including the building of roads and parking facilities. Divorce is out of the question because of our economic dependence; we must, therefore, reach an accommodation.

Because of a gradual awakening of the public to some of the problems, today we have many diverse groups engaged in an international struggle with the automotive industry in an attempt to regulate that industry for the "public good." Among these we find agencies of government, consumer groups, economists, engineers, environmentalists, insurance companies, legislative bodies and others—each group seemingly convinced that it can solve the problems. The main areas of concern are safety, economy and pollution. Unfortunately, there is less than unanimous agreement between the various interested parties about what constitutes a valid solution. There are apparently few in the many interest and pressure groups who understand the technical issues involved. For example, if some consumer group were to call for all automobiles to be constructed like the amusement park "bumper cars," the proposal would probably be greeted with open arms by some of our legislators, given a "why not?" acceptance or ignored by the general public and met with incredulous dismay by the engineer. (In addition, the engineers in the auto industry must contend with those in their own companies whose first interest may be style or, perhaps, something as prosaic as the financial success of the company. Vance Packard observed and Ford Motor Company proved with the Edsel that one does not determine the taste of the buying public by making surveys; such things are determined in the marketplace.)

RATIONALE FOR A COURSE

The elective course entitled "Vehicular Safety," offered by the Engineering Science and Mechanics Department at Virginia Polytechnic Institute and State University, was designed to fill two needs. First, students need to be better informed so that they will be better able to protect themselves on the highway. Second, although we sometimes tire of the cliché, students of today *are* the

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leaders of tomorrow; they need to be properly informed about the engineering aspects of the problems so that they can pass reasonable judgment on possible solutions.

It was decided that the course would not be restricted to engineering students but that interested students from all disciplines would be invited. This decision complicated both the problems of presentation and of evaluation because of the differences in technical background. The obvious solution to these problems was to use the backgrounds which the students brought with them. This precluded an approach employing complex derivations and mathematical rigor. The solution did not seem objectionable, however, because it was expected (as has been the case) that the main constituency would be engineering students who had completed statics, dynamics and strength of materials. The major challenge was to the instructor who would have to make complex truths and mathematical symbolism come alive and take on practical meaning for the class. That all of the students could be expected to have experience in driving and that they would be taking the course as an elective were considered to be positive factors.

Finally, since vehicular motion can best be explained (and *only* explained adequately) in terms of mechanics, it was decided that the Engineering Science and Mechanics Department was the proper setting for the course.

The course outline included the following general topics:

- a) safety improvements: past, present and future
- b) primary causes of accidents
- c) the laws of mechanics applied to vehicular safety
- d) statistics, in perspective, related to type and incidence of accidents
- e) techniques to reduce the probability of fatalities and serious injuries in accidents
- f) conflicts between safety and economy
- g) environmental effects and road hazards
- h) human behavior, response and tolerance
- i) special problems of recreational vehicles, motorcycles, mopeds and bicycles
- j) the effects of government regulations

MANNER OF CONDUCTING THE COURSE

One section of the course is taught in each quarter of the regular school year; it is not offered in the Summer School. It is a three credit course and has been taught both in the Monday-Wednesday-Friday sequence with three 50-minute periods per week and in the Tuesday-Thursday sequence with two 75-minute periods. Lately, the pattern of offering seems to be shifting more to the two period format to permit more discussion time when certain movies are used. Class size currently averages from 47 to 50 students with the largest enrollments in the Fall and the Spring. (See Appendix A for a listing of curricula represented in a typical section.)

Students are given a rather extensive set of multilithed notes because a suitable text is not available. The notes include raw and statistical data, diagrams, discussions of appropriate principles of mechanics, examples of applications of those

principles to safety problems and other pertinent information. Outside reading of related material is required; instead of specific reading assignments, however, students are encouraged to read in areas of their interests and concerns. Source material ranges from daily newspapers to research reports and frequently includes books and special interest magazines (e.g., "Motor Trend" or "Road & Track") as well as those publications which seek to "popularize" science and technology. Reports on outside reading are required.

Audio-visual aids are used extensively, partly because of class size and partly because of the nature of the course. These include 35mm slides, overhead projection transparencies, 16mm sound films and TV tapes shown on a classroom monitor. A number of excellent movies are available for loan or purchase. (See Appendix B for a listing of sources and titles of some of those which have been shown.) The chalkboard and traditional lecture methods are also used.

Student participation is encouraged at all times, both in classroom discussion and in bringing information to the attention of the instructor. Some class members have shared interesting and very relevant experiences both in and outside of class.

The evaluation of student performance in this course poses a few problems not present with other mechanics-oriented courses. The instructor must keep in mind the diverse backgrounds of his students and not be dismayed, for example, when the technical content (in terms of principles of mechanics) of a report by a Biology major does not measure up to that in a report written by an Engineering Science and Mechanics major. Conversely, he must know the students well enough to expect more mechanics from the Engineering Science and Mechanics major. (This sounds like an excuse for grade inflation—actually it is not because no excuse is needed. Students take the course because they are interested. Enthusiasm runs high and students—most of them, at least—*want* to do a good job on their assignments. Grading standards have stiffened and the quality of student performance has definitely improved since the course was first offered.) Course grade is based upon the instructor's evaluation of student performance on homework problems, several minor reports on assigned (general) topics, a major project report on a course-related topic of the student's choice and a comprehensive examination based upon the material discussed in class (including the various films, etc.).

The project upon which the major report is based must relate to some aspect of vehicular safety; that is, to the vehicle, to the driver, to the environment or to some combination thereof. The students spend, on the average, from 15 to 20 hours in research and report writing for this project. They are encouraged to find problems, to analyze those problems and to suggest problem solutions. A favorite topic for these reports is the so-called "booby-trap" problem in which the student finds something which is a potential hazard to the motoring public (or to pedestrians) and for which the endangered party either has no control over the problem or is unaware that a problem exists. Such things as design defects in automobiles, add-on accessories which create perilous situations and design defects in the highway environment have been studied in great detail. The continuing controversy over active versus passive restraint systems has attracted

a considerable amount of student attention, as has the very current concern over driver impairment. Students are urged to follow up on their projects by passing the information which they have gathered to the proper authority, either by personal contact or by letter. (See Appendix C for a typical listing of project report titles.)

MECHANICS CONTENT OF THE COURSE

As noted previously, the "Vehicular Safety" course was not intended to be known for its logical and concise derivations and mathematical rigor. Instead, principles of mechanics are discussed as simply as possible and used to explain physical phenomena or to solve problems. Great care is taken to illustrate lectures with examples drawn, whenever possible, from the common experiences of the students. Simple demonstration experiments of the type normally used in teaching sophomore mechanics or physics are employed as necessary to get a point across. Sketches, free-body diagrams and models are used freely. Students frequently have an intuitive feeling for many of the principles; a feeling developed by living and observing for twenty or so years.

The mechanics-related principles used include the following:

- a) Newton's laws of motion: concepts of velocity and acceleration; forces in equal and opposite pairs
- b) Coulomb friction
- c) energy concepts: transfer, absorption and dissipation of kinetic energy; elastic and plastic material response; heat generation
- d) impulse; momentum; impact
- e) fluid mechanics: lift; drag; turbulence
- f) biomechanics: human tolerance, reaction and response

The particular applications of these principles to vehicular safety which are examined in detail include such topics as "natural" or straight line motion; effects of radius of curvature and superelevation; effects of weight transfer and distribution in stopping and cornering; and problems of stability such as sliding versus rollover. Various restraint systems are studied in terms of load distribution on and change of momentum of the vehicle occupant. Considerable time is given to the relationship of size, crushing distance and energy absorption in vehicle impact. The aerodynamic effects of lift, drag and turbulence on stability and performance are considered. The problem of hydroplaning is examined with the aid of a NASA film; also, a film is used to study the problem of vehicle accidents (impacts) in which fire is a problem. Behavior of drivers and pedestrians is discussed in terms of reaction to prescription and nonprescription drugs, legal and illicit drugs (including alcohol), age, disease and mental state. Vehicle components which are most frequently cited as causes of accidents (i.e., tires, brakes and steering mechanisms) are examined in terms of both the design criteria and the proper care and usage. Lighting as a means of illumination and as a means of communication with other drivers is discussed; also, the problem of "over-driving" headlights by driving too fast at night is a rather simple exercise in motion which the students can handle easily and which invariably surprises most of them.

Because of the interests of this special age group, additional time is given to discussion of the motorcycle, moped and bicycle. The need for special clothing (including helmets), the problem of being seen, hazards of "choppers" and the problem of moisture on brakes—these and other problems are considered.

EVALUATION

The manner of conducting the course is currently much the same as it was in the beginning. There have been some shifts of emphasis and a few minor adjustments in evaluation procedures. On the whole, however, the original plan has proved satisfactory.

As expected, the majority of the students have come from the College of Engineering. Two engineering departments, Civil and Mechanical, permit the course to be used as a technical elective; the students in other engineering departments use it as a free elective. Students also come from other colleges, as shown in the list in Appendix A.

There has not been a formal evaluation of the course in the sense of data collection and statistical analysis. There are indicators, however, which lead to the conclusion that the students who have taken the course consider it to have been worth their while. Student comments about the course on the back of the current "Student Opinion of Teaching" form have been quite complimentary. Other feedback, in the form of student comments to the instructor (sometimes months after the course is over), indicate that the students feel that the knowledge they have acquired has been helpful and that an end product has been an improvement in driving habits.

There are positive indications that the students who have come into the course without a mechanics background have gained both an understanding of and an appreciation for the principles of mechanics discussed in class. The key to understanding has been the use of simple examples of physical phenomena from within the area of their common personal experiences. As for the engineering students, there has been an almost serendipitous revelation that the principles of mechanics apply to moving vehicles as well as to a block which weighs 143.2 Newtons (32.2 pounds) sliding down a 30° incline. It is no exaggeration to say that, for many of the engineering students, it has come as something of a pleasant surprise to learn that they can use their theoretical knowledge of mechanics in this very practical fashion.

APPENDIX A

Student Curricula Represented in Enrollments in ESM 3700-Vehicular Safety Fall 1976—Spring 1978 (6 Sections, 1 each Quarter)

College of Engineering (High 94.1%, Low 61.5%, Average 77.5%)
 Aerospace and Ocean Engineering
 Agricultural Engineering
 Civil Engineering

Electrical Engineering
 Engineering Science and Mechanics
 Industrial Engineering and Operations Research
 Materials Engineering
 Mechanical Engineering
 Mining Engineering
 Engineering Technology

College of Business (High 20.5%, Low 0%, Average 9.4%)

Accounting
 Finance
 General Business
 Management
 Marketing

College of Arts and Sciences (High 15%, Low 0%, Average 8.2%)

Biology
 Chemistry
 Communications
 English
 Geography
 Political Science
 Psychology
 Sociology
 Statistics

College of Education (Average 1.5%)

Business Education
 Industrial Arts Education
 Physical Education

College of Agriculture and Life Sciences (Average 1.4%)

Agricultural Economics
 Animal Science
 Forestry and Wildlife
 Horticulture

College of Architecture (Average 1.3%)

Architecture

College of Home Economics (Average 0.7%)

Human Nutrition and Foods
 Management, Housing and Family Development

APPENDIX B

Audio-Visual Aids Which Have Been Used in ESM 3700-Vehicular Safety

A) 16mm Films

<i>Title and Subject Matter</i>	<i>Source</i>
a) "In the Crash"—Overview of safety improvements in autos	IIHS ¹
b) "Small Car-Large Car Crashes"—Head-on collisions, standard size and compact autos	IIHS
c) "Cars That Crash and Burn"—Gas tank failures in rear-end crashes	IIHS
d) "Crashes That Need Not Kill"—Air bags	IIHS
e) "Booby Traps"—Built-in highway hazards	IIHS
f) "Hydroplaning"	NASA ²
g) "Dual Braking Systems"	NASA
h) "Rollover Tests"	NASA
i) "Motorcycle Crashes and Air Bags"	Colorado State Univ.
j) "Building in Highway Survival"—Design of crash barriers	NHTSA ³
k) "Lights Out"—Break away light standards	NHTSA
l) "Break Away Poles and Energy Absorbers"	NHTSA
m) "Biomechanics"	Wright-Patterson (Air Force)
n) "A Look at Air Bag Reliability"	Allstate Ins. Co.
o) "Levels of Danger"—Effects of alcohol on drivers (test with race car drivers)	North Carolina Dept. of Motor Vehicles
p) "Verdict at 1:32"—A clinical look at effects of alcohol (Strong stomachs recommended)	The International Temperance Assoc.
q) "Change by Design"—Design for Safety	Ford Motor Co.
r) "C.R.A.S.H."—Vermont countermeasures related to alcohol safety on the highways program	Ford Motor Co.

B) 35mm Slides

- a) *History of Safety in Car Advertising*—a collection of slides made from magazine advertising by automobile manufacturers

¹ Insurance Institute for Highway Safety

² National Aeronautics and Space Administration

³ National Highway Traffic Safety Administration

- b) *Technical Aspects of Tires*
- c) *Slides from student booby trap reports*
- d) *Slides from student reports on seat belts and bumpers*
- e) *Pedestrian impact sequence*

APPENDIX C

A Sampling of Project Report Titles for ESM 3700 Vehicular Safety

- a) Injuries and Forces Incurred by Wearers of Seat Belts
- b) Experimental Safety Vehicles
- c) Advanced Deployable Restraints
- d) The Air Bag Dilemma
- e) Impact Attenuators
- f) A Project on Seat Belt Testing
- g) The Role of the Physician in Preventing Traffic Accidents (Impairment Due to Prescription Drugs)
- h) The Other Intoxicant: Marijuana
- i) Positive Control of Kinematics
- j) Anti-Lock Brake Systems
- k) Vision: An Integral Part of Vehicular Safety
- l) A Survey of Rear End Impacts
- m) Close Encounters of the Worst Kind
- n) Driver Reaction Time
- o) Vehicle Modifications and Additions as they Pertain to Safety
- p) Hypnosis and Fatigue
- q) Trees—Safe or Knot?
- r) Automotive Improvements Through Aerodynamics
- s) Booby Traps in Lancaster County
- t) Windshields and Vehicular Safety
- u) Techniques Used to Measure Human Tolerance to Head Impacts
- v) Car Safety Restraints for Children
- w) Energy Absorbing Steering Column

APPENDIX D

Some Useful References and Information Sources for a Course in Vehicular Safety

- A) Specific Publications
 - Status Report* (current issue: Vol. 13); Insurance Institute for Highway Safety, Washington, D.C.
 - Proceedings of the "nth" Stapp Car Crash Conference* (current issue: 21st); Society of Automotive Engineers, New York.

- Vehicle Safety Research Integration Symposium*; National Highway Traffic Safety Administration, Washington, D.C.
- Proceedings of the International Conference on Automotive Safety*; U.S. Department of Transportation, Washington, D.C.
- 1968 Alcohol and Highway Safety Report* (appendix 1 consists of an excellent list of references to the problem of alcohol and safety); a report from The Secretary of Transportation to the House Committee on Public Works, 90th Congress; Superintendent of Documents, Washington, D.C.
- Proceedings of the "nth" International Conference on Alcohol and Traffic Safety*; Department of Police Administration, Indiana University, Bloomington, Indiana.
- "The Automotive Safety Belt Story"; American Safety Belt Council Inc., Los Angeles.
- Virginia Traffic Crash Facts* (annual), Virginia Department of Highways, Richmond, Virginia.

- B) General
 - Reports (on vehicle research); Cornell Aeronautical Laboratory, Buffalo, N.Y.
 - Various articles and reports, *Journal of the American Medical Association*.
 - Publications of various automobile insurance companies.
 - Publications of various state highway, motor vehicle and highway police departments.
 - Publications of various automobile and vehicle manufacturers.

The Place of Engineering Mechanics Faculty in Engineering Mechanics Programs

VERNE C. CUTLER

*Professor of Engineering Mechanics
University of Wisconsin—Milwaukee*

From various directions we hear of the attrition of significant aspects of Engineering Mechanics—departmental names, programs and courses. Therefore, is it not realistic to expect that serious undermining of our students' capabilities as engineers could well result if this erosion in quality is not stopped and reversed? Hopefully, it will soon become of real concern to appropriate organizations such as ECPD. However, the trend is not likely to change as we see by the current facts of life—Engineering Mechanics is not a "hot" area. Engineering administrators are under pressure to affect pseudo savings by consolidation of programs and also to bring in faculty in the "high temperature" areas. This, perhaps to the detriment of our students, may be accomplished by using mechanics courses to support the hiring of faculty in the other specialty areas—where there also happens to be a better probability of obtaining extramural funding. To show a modicum of fairness, I ask, can we fault administrators for going where the money is in these times of contradictory budgets? I say, contradictory, because enrollments are going up in engineering while support may be actually decreasing because of the negative over-all effect of enrollment declines in other units in the university.

But, contradictions exist within the ranks of Engineering Mechanics. For example, in the minutes of the ACDM (Association for Chairman of Departments of Mechanics) of December 7, 1976, concern was expressed over the declining interest and enrollment of students in classical mechanics graduate courses. It was agreed that the topic was worthy of a full and open discussion with all interested mechanics faculty. At that meeting of the ACDM, it was decided to include this topic on the agenda at some future meeting for the entire mechanics community. I think we all agree that was and is a fine idea! (I think

it would be an even better idea to do more than talk.) In addition, at one of the mechanics sessions of the 1977 ASEE meeting at the University of North Dakota, suggestions and philosophies were voiced that, to me, forecast serious trouble in Engineering Mechanics. Almost the same ideas were expressed at a previous meeting of ACDM at Northwestern University in 1973, with a response by me which appeared in a subsequent Newsletter of ACDM. What was it that aroused my concern? It was that we support an interdisciplinary approach to the teaching of Mechanics. Not really an idea to cause alarm was it? Of course, it was well intended but I say it may be or has been to the disadvantage of engineering students and Engineering Mechanics faculty.

Let me pause at this point to say that (1) I am deeply concerned about the future of Engineering Mechanics as it affects new students and faculty, (2) I am disturbed about the apparent indifference to the implications of interdisciplinary teaching in this area, and, (3) I do speak from some experience since I was chairman of a Mechanics Department and/or program for 15 years in a College where we still have 10 credits of Mechanics, on a semester basis, taken by *all* engineering students.

Now I would like to digress for a moment to tell you a story about a frog. If he is thrown into a pan of hot water a frog will jump out in a fraction of a second due to his instinct for survival. But if he is put in a pan of cold water which is then heated very slowly, he will not attempt to jump out. Instead he will relax so completely that he boils to death. Do we not have an analogy in Engineering Mechanics? Wouldn't our reaction be more energetic if we were aware of the possible outcome?

I would like to continue now with some thoughts and suggestions relating to several aspects of our role as professional teachers of Mechanics, the complementary relationship of research, some political considerations, and how ECPD could (and in my opinion, should) intercede to maintain the necessary depth and quality in the teaching of the required basic undergraduate Mechanics courses—Statics, Dynamics, and Strength of Materials.

Let's go back to my observation about interdisciplinary teaching. Is it a good idea to use Mechanics as a vehicle to support faculty in other areas (even with the best of intentions)? Is this in the best interest of the students? Not in my opinion. Engineering Mechanics should be taught from a basic viewpoint by competent professionals whose primary interest was and is in Engineering Mechanics and who have some practical experience in engineering. Individuals with these credentials have what it takes to provide a solid foundation in our area. We have something special to offer in terms of mental discipline, logical organization, and practical application. We have to make this clear to the academic community in general and the engineering administration in particular. We must dispel the illusion that others can do an adequate job of teaching the basic Mechanics courses if we want to restrain engineering administrators, who are under pressure to be cost-effective, from using Mechanics courses as a convenient basis for hiring faculty in non-related but currently popular areas. Mechanics would be in a much better position than it is today if more of us were concerned about the role of Mechanics as a part of a sound engineering program.

It's my conviction that the responsibility for teaching Mechanics courses, including the basic undergraduate courses in Statics, Dynamics, and Strength of Materials, belongs to the Engineering Mechanics faculty. If we can't agree on that, perhaps we don't deserve to exist as a separate entity! Of course faculty with good and professional backgrounds in related areas can and should assist in teaching some of the Mechanics courses. But they cannot replace and should not become a substitute for professional Engineering Mechanics faculty.

How do we view research? There's little I can say that you haven't heard a thousand times before but sometimes repetition serves to shake the barnacles off our perspectives. Meaningful well selected complementary research and activities may improve our teaching ability. However, the best researchers are not always the best teachers at all levels. Let's associate the talents and interests of our Engineering Mechanics faculty with the level of the courses they are teaching, whenever this is feasible. Mismatches benefit neither the students, nor the faculty and they do not enhance the appeal of Engineering Mechanics.

Now to a touchy subject—politics. There is an understandable reluctance to talk about the political aspects of our professional accomplishments. However, we need to hear more talk about specific accomplishments in curriculum structure as well as the history of battles won or lost. It may be just as important to know why a battle was lost as it is to learn how the war was won. What positive steps can we recommend as a result of our previous experiences? It's well to recognize that it may require a certain amount of political skill to maintain the established position of Engineering Mechanics in engineering programs. We must also stress the inherent practical value of Statics, Dynamics, and Strength of Materials whenever and wherever we can. This applies also to our individual contacts with the professional and industrial world.

Here are a list of suggestions you may wish to consider:

1. Meet with your colleagues in Mechanics at the departmental, regional and national levels to discuss plans, troubles, worries, setbacks and accomplishments that relate especially to the academic and engineering aspects of mechanics.
2. Solicit innovative ideas from other schools and seek out other faculty at various meetings to engage in round table rap sessions about Mechanics. Certainly the annual ASEE meeting would be a good place for one or two informal sessions to talk over not only the accomplishments but also the "cloak and dagger" activities associated with them.
3. Discuss why the teaching of Statics and Dynamics should *not* be an interdisciplinary effort or, to be painfully fair, why some may think it should be, at meetings wherever they may be. My personal conviction is that we serve our students and profession best by assigning experienced Mechanics faculty to teach Mechanics courses whenever this is possible.
4. Be aware of the value of having a designated undergraduate engineering program in Mechanics in order to retain or maintain the position of Mechanics courses in engineering programs. We should not accept the misleading appearance of numbers because the enrollments in under-

graduate Mechanics programs are usually small. Instead, demonstrate how the program would exist anyway because of the need for the individual courses.

5. Consider how we may be failing as teachers of engineering students. Have strong theoretical research faculty taken basic concepts so much for granted that they may underestimate their necessity and value? Do we depend on the "scientific" approach too much just because it's maybe easier to present? Vector notation, for example, may be an imposition of the scientific methodology at an inappropriate time in the case of statics. How many of you share my experience with students who used the dot and cross product, made a mistake, and accepted the erroneous result when the solution was obvious from the physical situation? I believe engineering students are more receptive to tangible methods than abstract mathematical operations.
6. Include the workshop approach when teaching the first course in Mechanics. I have found a marked improvement in the accomplishments of my students when 4 to 6 hours per week of additional sessions were scheduled to work problems (done by the student) instead of scheduled office hours. The side benefits include a better rapport with their instructor as well as a much healthier attitude about Mechanics.
7. Suggest including professionally stimulating additions to Mechanics programs and courses to give greater engineering meaning. Show the students what they can do with it. Who wants these students? Let the students know. Where have Engineering Mechanics graduates found jobs? Doing what?
8. Provide separate directions at some stage in the program for those who wish to become researchers as distinct from those who wish to be professional trouble shooters or consultants.
9. Select textbooks that are stimulating and informative from the viewpoint of the engineering student rather than select them to impress one's colleagues! The same might be said to those who write textbooks.
10. Explain the role of the professional Engineering Mechanics graduate as a trouble shooter or consultant, as an expert witness in accident and product liability cases, and their involvement in mechanical and structural failure situations. Also include theoretical and applied research opportunities. Do this through seminars or by sprinkling anecdotes in with the instruction of basic courses in Mechanics to interest and stimulate the students! If experienced professionals are not among the Mechanics faculty, then bring them in on a selective basis. Let us admit that no one can do everything. Therefore, even some of our most respected academic researchers are not necessarily the best qualified to speak on matters of a professional engineering nature.

This list will serve to remind us of what we already know. What I have done is to assemble a collection of suggestions that may be well established realities as far as you are concerned. I hope that is true. Certainly I'm sure you agree that

we must do whatever we can to improve the role of Engineering Mechanics in engineering programs.

Let us hope that ECPD will recognize the inherent danger of the current trend and restore the former emphasis on engineering fundamentals. I hope that there will be as much concern for this as ECPD has shown for the design aspects of engineering programs.

As a point of interest, our college was reviewed by ECPD this past year. I mentioned my concern about Engineering Mechanics and the eventual reduction in quality because of the loss of protagonists for this area. One member of the review team came from a school which recently abolished its Mechanics Department and assigned the Mechanics faculty to the Civil and Mechanical Engineering Departments. He did not share my concern because for the Mechanics courses at his school the same Mechanics faculty was still responsible for the Mechanics courses. But what happens when these protagonists leave or retire? If it is necessary to abolish a Mechanics Department it is essential to provide a mechanism for the responsible supervision of Mechanics courses by those best qualified to do so regardless of what department they may be in. This is why I so strongly support the proposed guidelines for ECPD Visitation teams in evaluating Mechanics courses for the B.S. Degree in Engineering prepared by the Committee on Accreditation of the Mechanics Division of ASEE, especially item 3, which reads:

"These courses should be under the supervision of engineering professors who normally hold at least a B.S. degree in engineering from an ECPD accredited curriculum or its equivalent. All of the important decisions such as those regarding textbook selection, course outlines and objectives, grading standards, and evaluative procedures are to be made by those engineering professors whose previous interests, expertise, and scholarship record lie in the field of mechanics."

This is the best way to maintain the quality and integrity of Engineering Mechanics and Engineering Mechanics courses in engineering programs.

THREE SCORE AND TEN

Mechanic's Dinner ASEE Annual Meeting

15 June 1976

Archie Higdon

Your speaker was born in October 1905 in a log cabin in the clay and gumbo hills of Mercer County Missouri—the "Show Me" State. (He graduated from South Dakota State University in 1928 with majors in mathematics and speech.) In his junior year he taught a trailer section of mathematics each quarter using the procedures he learned from his freshman mathematics teacher—Dr. Brown a master teacher and Vice President of the University.

During 1928–30 he was a graduate assistant in mathematics at Iowa State University where he met Alice Mae Cole and incidentally obtained an M.S. in Mathematics. Full time teaching followed at North Dakota State 1930–34 with marriage to Alice Mae on Labor Day 1931 (7 September).

He attended mechanics classes to learn first hand what mathematics his students needed for their engineering programs and sometimes found it necessary to help the teacher or the students solve the problems.

Langer was Governor of North Dakota and in 1932 he decided all faculty members should contribute 5% of their salaries to his political slush fund. The teachers refused so he slashed salaries and the North Dakota schools lost their accreditation when he fired many of the administrators. The Higdon's returned to Iowa State in 1934. Archie taught mathematics part-time and completed a Ph.D. in applied mathematics (really mechanics) under Dr. Dio Holl in 1936.

Archie joined the T.&A.M. faculty at I.S.U. in the fall of 1936 and learned that the letters stood for Theoretical and Applied Mechanics to the faculty and for Torture and Applied Misery to the engineering students. Higdon attended the North Midwest Section of ASEE each fall and began to participate in the activities of that active section. Frank Lightburn and Higdon soon began to talk about writing a textbook to sell their ideas about the teaching of mechanics.

Then the war years put both men in uniform—Higdon's time was August 1942 to July 1946. Lightburn elected to stay in California after the war but the Higdon's took their three daughters back to Iowa instead of accepting a military career offer.

After Higdon recovered somewhat from all the mechanics he had forgotten during those war years in the U. S. Army Air Corps, William B. Stiles and he decided (one fall day in 1946 on the I.S.U. golf course) to write a textbook. After three years of study and debate and writing and reading their first hard back edition reached them the day before Christmas 1949.

Textbooks were smaller then—as he recalled they included about what the students were supposed to master in the allotted time. Higdon compared his 1925 Calculus book by Love, Clyde E. of 367 small pages to Protter/Morey 1966 of 897 much larger pages. He also compared the Higdon & Stiles First Edition of 1949 with 505 pages to their new second vector edition with 799 pages and remarked that textbooks now seem to include all the information the teachers (writers) have or consider useful.

Higdon then shifted to some “first person” comments on the National Studies of Engineering Education as follows: The Mann report of 1918, the Wickenden Investigation of 1929, and the two Hammond Studies of 1940 and 1944 were effective in pointing up improvements that had been made and actions that needed to be taken at the time. Since I do not have personal information on these reports I will start with the Grinter Report.

In 1952-55 Dr. L. E. Grinter was Chairman of an Evaluation Study of Engineering Education. Two aspects of the Grinter study stand out to me. The Bifurcation proposal that was rejected and the identification of certain subjects as engineering science that was accepted. Bifurcation called for two types of undergraduate programs—one applied programs in preparation for entering industry at graduation and the other more theoretical programs in preparation for graduate study and research work. In 1963-67 the Goals Study of Engineering Education was made. In the fall of 1963 President and Dean F. L. Partlo of South Dakota School of Mines & Technology confessed to me (I was field man for the undergraduate portion of the Goals Study) that he strongly objected to bifurcation when it was proposed by the Grinter Study Group but that he realized later that he was wrong. Others agreed but the Goals Group did not revive the term or the concept.

In 1964 Harold A. Foecke, Dean of Engineering at Gonzaga University advocated a Bachelor of Engineering Technology program. I admit speaking against that concept in 1964-65 and then starting such a program at Cal Poly in 1968-69. Who knows whether Engineering Technology is a better or worse solution than Dr. Grinter and his team had in mind with bifurcation some 10-15 years earlier. The engineering science proposal of the Grinter Study resulted in many changes in engineering programs and much study and debate. Engineering mechanics faculties were really involved in the dialogue on engineering science over the years.

Higdon & Stiles came out with their Second Edition in 1957 which was widely accepted even though it did not shift emphasis to a more mathematical approach. Then in 1958 Irving Shames, Professor and Head of Interdisciplinary Studies at SUNY Buffalo came out with his Vector Mechanics and the many debates over how much higher mathematics should be included in beginning mechanics were the order of the times. Lath Meriam, Beer & Johnston, and others were

very actively involved in all this activity. Beer & Johnston published a vector edition in 1962 as did Higdon & Stiles. Lath Meriam waited until 1966. All three texts stressed physical understanding and applications over more mathematical concepts.

In order to provide the increased emphasis on the engineering sciences most engineering faculties reduced graphics and reduced or eliminated shop courses. This change of emphasis was not considered popular with industry but no organized objections were raised as I recall.

The Goals Study reaffirmed the emphasis on the engineering sciences and thereby perhaps encouraged those engineering faculties with Ph.D.'s and little or no industrial experience to move to more and more theoretical and less applied engineering programs. This trend certainly created more need for bifurcation under its current name of Engineering Technology.

The voice of industry was never, in my opinion, really presented effectively during the Goals Study. I tried in Colorado, with the active encouragement of Dr. George Hawkins, Director of the undergraduate portion of the Goals Study. Industry was willing, but not eager, to help. It took a lot of time and effort to set up a conference in one organization and then the industry people did not, or perhaps could not, speak with one voice.

On the other hand the engineering college faculties (168 accredited at that time) with one exception where the Dean would not allow me to talk with his faculty, wanted to hear and be heard. Most institutions wanted an entire day spent on their campus except for a few big city institutions that were happy to confine the visit to 2-3 hours. Each institution had a faculty committee confer with the Goals field representative when he arrived.

In summary I believe that many, perhaps most, engineering programs moved too far toward the theoretical aspects of engineering with too little applied engineering retained. This view is based on frequent comments from both engineering faculty and engineers in industry.

Right now I suppose the rate of change to metric units is much more current than the problems I have mentioned. Furthermore the problems related to the sources of energy are certainly more critical.

The ancient and current debate over how much specialization is justified in undergraduate engineering programs is still around. Many of those who believe in a high degree of specialization will continue to call for reductions in mechanics courses and having their students take most all of their courses from the professors in the student's area of specialization, etc. to build their own empire, keep their faculty busy and their major students' grades high.

Self-pacing programmed material. Clyde Work and Lath Meriam work with students at the students' own rate of learning along with tests to make sure they understand the material studied.

For me—Retirement is Wonderful—Thank you.

NOTES